SCIENCE TEACHING: MATTER, ENERGY AND MACHINES

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CHAPTER 1: SCIENCE, SOCIETY AND EDUCATION

1.1. Types of human knowledge. Scientific knowledge

According to Jorge Wagensberg, there are at least three types of human knowledge: scientific knowledge, artistic knowledge, and knowledge by revelation.

Scientific knowledge is based on three axioms: the world is understandable, the world can be objectified, and there is a dialectic between the world and the mind (empirical experimentation). Therefore, there is an advancement of science (and technology).

Artistic knowledge is built on an axiom: minds can communicate through unintelligible complexities. These unintelligible complexities are the works of art (and the emotions they elicit). Art does not necessarily advance. Emotional awareness is very similar to artistic awareness.

Knowledge by revelation is based on three principles: there is a 'being' by whom everything is understandable. Everything is objective. On the other hand, the 'being' wants to let us share his knowledge.

Science is a human construct (of the human brain), collective, and intended for everyone (and not for an elite). We must be careful at school not to make it 'artistic knowledge' (based on mere subjectivity) or 'knowledge by revelation' (based on belief or faith in someone or something) because it would lose its educational mission.

1.2. Scientific literacy

Scientific literacy 'is seen as a civic competency required for rational thinking about science in relation to personal, social, political, economic problems, and issues that one is likely to meet throughout life' (Hurd, 1998: 410).

Experts consider that scientific education has different goals:

1. Encourage citizens to participate in political and social decisions in a technological society (**social goal**).

2. Prepare people who have a special interest in future studies in science and technology (**propaedeutic goal**).

3. Give an adequate preparation for the current job market (**labour goal**).

4. Stimulate moral and intellectual growth in pupils (**formative goal**).

Miller (1998) determined three dimensions within the concept of scientific literacy:

a) Knowledge about science:
    a1) conceptual knowledge.
    a2) knowledge about science processes.

b) Knowledge about the nature of science (NOS): what is scientific knowledge, how it is produced, and how scientific knowledge is validated and accepted.
c) Understanding and controlling the impact of science and technology on society.

1.2.1. A little history about scientific literacy

As explained by López Sancho (2002) in the morning news on 4 October 1957, the Americans discovered there was a new celestial body in the solar system and the Earth had a new satellite: Sputnik. The United States had a team of German scientists led by Von Braun, the world's most advanced rocket specialist, who had been in the country since the end of the Second World War. The American people, convinced that they had the most advanced technology, suffered a tremendous disappointment. This type of disappointment and the reactions they triggered are important and indicative in the history of nations. Spain had suffered on several occasions: the defeat of the Invisible Armada or the loss of Cuba and the Philippines in 98 are good examples.

The reaction of the United States was swift and effective. Congress addressed the scientific institutions, both official and professional, as well as large companies and demanded reports on the origin of the technological delay revealed by Sputnik. The answer was immediate. A stage of social introspection and research began in science teaching. Anyone who was able to analyse the problem and contribute with solutions received funding for research. The results of the analysis can be summarised in the following points:

a) American citizens conceived science as something extremely useful, but mysterious and complicated in nature, and almost impossible to understand by non-specialists.

b) They understood that science had been decisive in winning the Second World War (with advances such as radar and the atomic bomb) but did not see the need to continue the effort in large-scale scientific research.

c) They were afraid of the possible effects of the application of unknown and unpredictable scientific discoveries. The lack of knowledge made the development of new forms of production difficult, especially when they implied qualitative changes in scientific foundations.

As a result, American society came to a clear conclusion:

The problem of technological lag was because the average citizen was scientifically illiterate

The solution that was reached was synthesized in two slogans coined by the American educator Jerrold Zacarias:

- Science is for all Americans
- Science should be something that students do, not something they receive ready-made (this was a revolution in teaching and methods).

The problem, although clearly diagnosed, was serious and difficult to solve. But in one thing teachers, psychologists, sociologists, and scientists agreed: the cause was that science, not being included among the disciplines taught in childhood, did not form part of what was endearing, familiar, and loved. Neither disciplines, nor their methods, nor the taste for understanding the world, were found in the fundamental nucleus of children's education. The solution was obvious: we had to start teaching science at schools.

This required political action. It was necessary to establish the scientific content to be taught at schools, and teacher training also had to be modified (both the training of the new generations and of those who were already teaching). Thus, in 1966 the *Elementary Science Study* and *Science Curriculum Improvement* laws were enacted, which made science teaching compulsory in the 5 to 13-year period.

These laws were followed by innumerable projects. The organisations that were most involved were the American Association for the Advancement of Science, the National Science Foundation, the National Academy of Sciences, and the American Physical Society.

A few of the most important milestones were the publication of *Benchmarks for Science Literacy* in 1993 by the American Association for the Advancement of Science, with the minimum contents that were considered essential to consider a person scientifically literate. The publication of the *'National Science Education Standards'* in 1995 by the National Research Council or the publication in 1997 of *'Science for all Children: A guide to improve science education in school'* by the National Science Resources Center. The bases on which all these actions are based were explicitly stated in all of them:

- It is essential to achieve the scientific literacy of citizens
- The desire to continue acquiring scientific knowledge must be developed throughout life
- Content should be limited, moving away from the classic way of treating 'a mile-wide and inch-deep' tracks.
- Learning is like the historical process of discovery; teaching is nothing more than a quick journey through the history of mankind and, in our case, from the history of science

The second problem was as important as the first:

How do you teach science to teachers and how do you keep them up to date when qualitative changes occur throughout a professional life?

The American Physical Society and the American Association of Physics Teachers, among other organisations, concluded that technology and science advance too quickly for the original training that teachers receive at the university to be valid during the active life of a teacher. There is a need for a continuous training. This is only achieved by involving teachers and researchers in common tasks, in projects that keep them in touch and make them interested in each other's problems. Because, in Feynman's words, when we do not know how to explain a subject using elementary mathematics it is because we do not master the subject sufficiently.

In 1963, the American Association of Physic began publishing 'The Physics Teacher' so that researchers and teachers could publish together.

1.2.2. Advances in understanding the construction of science

Since learning is like the historical process of discovery, there is a need to study how science is created to understand its difficulties and apply them to the parallel process of teaching.

The most important results were achieved in the field of history and philosophy of science. Thanks to the investigations carried out in the second half of the twentieth century (almost entirely by physicists), a clear idea was conceived about the nature of knowledge, about what science is and what it is not; the way in which scientific advances are produced and how to encourage them, and how they are absorbed by society.

1.2.2.1. Popper and the test to distinguish between science and pseudoscience

Karl Raimund Popper was educated in the Austrian capital in the 1920s in an environment in which the inductivism of the so-called Vienna School prevailed. He tells us how he was disenchanted with that idea. Basically, inductivism considers that the laws of science are built directly, in an almost automatic way, on the results of the experiments. Popper explains how both Marxists and Freudians explained the same facts by means of their two theories (so disparate), and both concluded that the explanations were correct. Popper concluded that the two theories were flexible enough to accommodate any historical or human behaviour, giving the false impression that they explained the facts.

Popper compares this situation with the completely different way in which the scientific community raised the verification of Einstein’s general theory of relativity. The theory predicted that light, when propagating, should feel the action of gravity like any other form of energy and consequently its path should curve as a body passes near to large masses such as the Sun. Consequently, an observer pointing his telescope to a star would see it in different positions if the light rays passed near the sun than if it was not in the way. Eddington, in 1919, carried out this experiment during an eclipse and found that the results agreed with Eistein’s predictions and, consequently, the general theory of relativity was accepted.

Popper gave the concept of experimental testing a new interpretation. The important thing was not the fact that Eddington’s observation implied the validity of the general theory of relativity, but the general theory of relativity was capable of being verified. There was a well-established procedure, that could show if a given theory was false. And Popper used this possibility of ‘fallibility’ as an essential characteristic that served to separate beliefs, explanations, and theories in two categories: scientific and pseudoscientific. Karl Popper’s new approach was gaining followers and today the scientific community takes it as the ‘test’ that differentiates, separates, and distinguishes science from pseudoscience.

1.2.2.2. Kuhn and the essence of scientific advances

Thomas Kuhn published his book, *The Structure of Scientific Revolutions*, in 1962 and added an addendum in the 1970 edition. In the same way that Popper focused on the nature of a theory, Kuhn studied the characteristics that it must present to produce a revolution in science.

Kuhn's fundamental idea points out the revolutionary character of progress in the science, which does not consist in a simple accumulation of knowledge, but in a change of scientific paradigm, that is, the way scientists see reality.

We can illustrate this idea by studying the Galilean revolution. Until the twentieth century, the paradigm or scientific framework was that of Aristotle, who presented the universe as divided into two parts with different natures and with the Earth in the centre: the imperfect, corruptible, and changing part of the universe that reached the sphere of the Moon and the perfect, immutable, and incorruptible universe which extended beyond lunar sphere. But it was Galileo's interpretations of the observations of Ticho Brahe, as further developed by Keppler, and of his own observations by telescope, that destroyed the paradigm by imposing the new qualitatively different vision that been called Copernican.

It is a fact that the scientific community (among other communities) reacted violently when faced with that paradigm shift. We can quote Lord Kelvin's words to in this regard: 'science advances because the scientists of a generation die and the young people of the next generation study new ideas before becoming contaminated with the old ones, thus not having to go through the painful experience of changing their minds'.

1.2.2.3. Derrida's idea of reconstruction

Jacques Derrida entered the history of philosophy in 1966, with a lecture he gave at John Hopkins University entitled 'The structure, the sign and the game in the discourse of the human sciences'.

Derrida's deepened the idea of Kunh. Derrida projects onto the human being what Kuhn does in the history of science, unraveling the nature of the reaction (always contrary and sometimes violent) with which affected communities have almost always welcomed a revolutionary idea. For Derrida, the paradigm is a psychological frame that, like glasses interposed between thought and reality, prevent us seeing the world in a new way. The idea is illustrated particularly well with the well-known image of the cup and the faces we've all studied in psychology.

The brain works in such a way that if we see the cup, we do not see the figure of the face and vice versa. In the example of the Galilean revolution, we can assume that the scientific community was divided between Aristotelians and Copernicans, who would correspond in our example to 'cupists' and 'facists'. Only after a period of seizure, where even the Inquisition played its role, the 'cupists' were able to 'see' the faces, and this produced a qualitative advance of science, or a paradigm shift. Once we discover the faces, we cannot explain how we could not have seen them before.

Derrida, in his lecture and later work, sets out his idea: what is fundamental in a revolution is not discovering and building that which is new, but destroying (he calls it 'deconstructing') the previous erroneous knowledge: or what in teaching is called a preconception. This 'deconstruction' is only achieved by a combination of crucial experiments, such as the ones by Eddington or Michelson, with the speeches of a Galileo or an Einstein, and probably with the passage of a generation, as Lord Kelvin said.

There are many examples of this difficulty in changing the paradigm in human activities. Darwin's theory of evolution, equality between men and women and different races, and the injustice of slavery are ideas that now surprise nobody but were originally difficult to accept.

1.2.3. Scientific literacy in Europe

The example of the United States was followed in Europe and in 1972, six years after the early American legislation, the United Kingdom enacted 'Science 5/13', the first law to make science teaching mandatory in school. This was followed by many others and all the countries of the European Union now have similar legislation.

In our continent there is awareness that the only way to put into practice these teaching approaches is by scientists and teachers collaborating closely. In France, G. Charpak (1992 Nobel Prize in physics) pointed out in 1995 the desirability of scientists taking an active part in early-stage education. As a result, various research and teaching organisations launched a series of actions included in the operation 'La main a la Pâte', which has now been transformed into a collaborative tool of French scientists and teachers for school science teaching. Collaboration is implemented in classes, conferences, and classroom applications and is supported by a permanent website: http://inrp.fr/lamap/main.

Similarly, Leon Lederman (1988 Nobel Prize winner in physics), spoke passionately last September at the meeting of the Portuguese Physical Society about the need to introduce science into school to prepare students for the world in which they will live. According to Lederman, teachers are the key to science teaching. But, according to their experience, they may not have the necessary knowledge to fulfill this task. R. López, director of education for the American Physical Society, wrote an article in 'Physics Today' this September in which he concludes that students should 'do' science and he discusses the form and the institutional aids available. Finally, in the September issue of this year, Catherine Wilson, head of the department of education at the Institute of Physics, discussed what should be the master lines for teaching physics in school, pointing out that it is a fundamental stage for the training of pupils and students.

1.3. The study of science in primary education and early childhood education

Science in primary school is at the service of the education of citizens. What is important is its educational potential, more than the content itself (although you cannot educate in the absence of content).

If we look at the different modes of intelligence and consider the primary curriculum as a whole, we see that science can be used to develop skills associated with the application of logic to world problems; with rigour and the requirement of proof when making important claims; the perception of deception in advertising and/or political messages, among others; the possibility of understanding non-verbal forms of expression (such as graphics) or complex reasoning for making important decisions. In the same way, the arts in primary school can favour sensitivity and emotional education, while physical education can promote healthy habits and caring for the body, while languages can develop the brain, communication skills, conceptualisation, and promote understanding of other cultures. According to Gardner's theory of multiple intelligences, different subjects seem more appropriate for developing each mode of intelligence.

Interest in scientific education extends throughout the Western world. The World Conference on Science for the 21st Century, sponsored by UNESCO and the International Council for Science, declares that:

> For a country to be in a position to meet the fundamental needs of its population, the teaching of science and technology is a strategic imperative. Today more than ever it is necessary to promote and spread scientific literacy in all cultures and in all sectors of society in order to improve the participation of citizens in decision-making regarding the applications of new knowledge. (UNESCO, 1999)

National Science Education Standards, favoured by the National Research Council (1996) for the achievement of the scientific education of twenty-first century American citizens says on the first page:

> All of us have a stake, as individuals and as a society, in scientific literacy. An understanding of science makes it possible for everyone to share in the richness and excitement of comprehending the natural world. Scientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society. A sound grounding in science strengthens many of the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning. And the economic productivity of our society is tightly linked to the scientific and technological skills of our work force. (Research Council, 1996: 1)

Scientific knowledge helps us to:

- Understand the critical issues found daily in government news and debates.
- Appreciate how natural laws affect everyday life.
- Gain perspective on the intellectual climate of our time.

1.3.1. Education from science

Education provides well-being by instilling a common set of values in all members of society. Educating is a long process and includes other similar concepts such as instructing, training, and indoctrination. **Instruction** does not have to carry values. **Training** pursues an appropriate behaviour before a situation or an order from an authority (a mother, a teacher, etc.). **Indoctrination** involves inculcating an ethical code associated with emotions to shape the consciousness of the individual in line with the consciousness of a leader (who may be the mother).

School subjects are at the service of education and not the other way around. They are not an end in themselves but a means of getting people to acquire certain values.

To educate is to transmit and make possible the internalisation of socially and legally consensual values. Some of the values that should be transmitted by the educational system (including parents, naturally) include: responsibility (linked to freedom); respect (linked to equality); fraternity (linked to solidarity); honesty; courage; good manners; wisdom (without which, other values are difficult to absorb); empathy; tolerance; humility; and (self) critical capacity.

The values that science, *per se*, can transmit are those that have been associated with the working techniques of scientists, the type of knowledge that is intended to develop, and the use made with that knowledge. For example, Nicholas Rescher, in his book *Reason and Values in the Scientific-Technological Era*, considers that the values of science are linked to:

a) The objectives of science: the tasks of scientific research are always linked with evaluations, for example, the topic of an investigation is chosen by individual subjects or by groups, but this choice is always made by giving preference to some topics over others and considering the investment in time, effort, and resources. The conduct of the researcher is linked to values such as **truthfulness**, **precision**, and **objectivity**. The same happens with the effective description, prediction, control, and mastery of nature that translates into technology.

b) Values of science in terms of theory. Certain value factors constitute the desiderata of scientific theories, and include (in addition to the creation of **wisdom** itself) the factors of **coherence, consistency, generality, understandability, simplicity, accuracy, and precision**. Here are also the values included in the management of cognitive risk, especially the standards of proof and rigour in the considerations that serve to determine how much empirical evidence is required to justify the acceptability of certain scientific statements. Merton long ago pointed out that **universalism** (validity of knowledge and procedures regardless of race, beliefs, culture, etc.) as a value sees in impersonality the responsibility for finding the degrees of truth (validity) within science – and not outside of it.

c) Values of science in terms of the production process: values inherent to scientific workers, that is, to the actors themselves, such as creativity and originality, perseverance, persistence, truthfulness, intellectual honesty, attention to detail, passion for the search for truth, intellectual modesty, humility, organised scepticism (to examine and judge knowledge regardless of beliefs and opinions), and disinterest (testable impartiality according to Merton). Here also we should include the stimuli for the researcher and the search for incentives and rewards by the researcher.

d) Values of science in terms of application: Merton stated that social collaboration was an essential value of science communism (which defines knowledge as a collective property). That is, scientific knowledge must be given to all humanity once produced. Some value factors represent **the benefit of the products of science**, mainly related to its application to the advantages of human desires, such as **well-being**, **health**, **longevity**, **comfort**. This is especially true when speaking of sciences like medicine, agriculture, and genetic engineering. In these sciences, above all, we find the ways through which values permeate the scientific-technological work, for example, when evaluating the desirability or not of various technological implementations by asking (doubting) whether it is desirable (ethically or morally) to carry out psychological manipulations, organising pressure groups to guide opinion, and develop weapons of mass destruction. Questions about cloning and abortion arise in various areas of medicine such as euthanasia and the artificial prolongation of life.

1.3.2. Values that can be worked on at school

1. **Curiosity**. Albert Einstein said: ‘The important thing is not to stop questioning. Curiosity has its own reason for existing’. We should make it easier for pupils to ask about things related to specific educative goals

2. **Rationality**. Understanding as a respect for logic, as well as the need to consider antecedents and consequences of each phenomenon analysed. This is the basis for searching for the causes and motives for phenomena. For example, a rational person is not superstitious.

3. **Scepticism**. Science promotes the search and demand for tests, and the continuous evaluation of knowledge with a critical spirit. In science, everything must be questioned and honesty is essential, because sooner or later the reality of the facts prevails.

4. **Relativity**. This is closely related to scepticism and describes the need for nuances that a quality in the affirmations needs. The uncertainty and limitations of results, the margins of error, and the edges of uncertainty are common areas in science. Traveling through them educates us in the understanding of risk levels, and the ability to evaluate a priori the success or failure of an initiative.

5. **Self-criticism**. It is essential in science to doubt any conclusion that you formulate yourself, and to immediately begin looking for your weak points. Science is critical of

itself, and it also must be open to social, historical, and cultural scrutiny – both by intellectuals and society in general.

6. **Opening**. The availability to listen and accept ideas from others, and to change our own ideas based on the evidence offered to us. Openness is essential for innovation and for creativity to bear fruit.

7. **Initiative**. The need for continuous review of science and the permanent possibility of improving technological solutions requires an attitude of nonconformity and enterprise. There must be an assessment and assumption of risks in innovation. Learning from failed tests is an essential and useful step in a process.

8. **Creativity**. It is key in technology to seek solutions to problems, think in a divergent manner, and establish original relationships, design experiences, propose hypotheses, invent and design laws, and create models, theories, devices, mechanisms, procedures, and methods.

Science does not consist only in current knowledge about the world, but also in the methods followed for the creation and validation of that knowledge. The cultural contribution of the method is very important and raises awareness of the potential for fraud, deceit, lies, pseudo-reasoning, biased use of data, false prophets, etc.

1.4. The image of science

Future teachers must be aware of their own attitudes towards science (and towards the study of science) to avoid reproducing behaviour (often unconsciously) that demotivates pupils. This implies the selection of valuable and meaningful content, and an educational method that enables pupils to construct knowledge (as opposed to accepting knowledge transmitted by authority) in creative and challenging ways.

Drawing from original DAST study (source: Yewhoenter, Wikimedia Commons)

There are often distorted views of science and scientists, such as the following:

a) **A problematic and an ahistorical** (dogmatic) **view** is provided when already knowledge is transmitted without showing the problems that its construction generated, how it evolved, and the difficulties and limitations of current knowledge.

b) A **linear and cumulative view** of the development of science which does not show the breaks with the accepted ideas and forgets the existence of crises and profound remodelling.

c) **An individualistic and elitist view** is influenced by showing scientific knowledge as the work of isolated geniuses, ignoring the role of the collective work of generations. Scientific work is also presented as a domain reserved for specially gifted minorities, transmitting negative expectations towards students, with certain social and gender discrimination (science is presented as an activity for men).

e) An **empirical-inductivist view** emphasises the role of ‘neutral’ observation and experimentation (not contaminated by *a priori* ideas) and luck. It forgets the essential role of hypotheses as guidelines and a focus of an investigation, and the role of the coherent bodies of knowledge (theories) guiding the entire process.

f) A **rigid view** (accurate and infallible), where the ‘scientific method’ is presented as a set of steps to be followed mechanically. This view highlights quantitative treatment, rigorous control, and overlooks everything associated with invention, creativity, and doubts.

g) A **socially decontextualised view** of the world's problems that ignores, or superficially deals with the complex STS relationships (science-technology-society, or, better, STSE, adding the ‘E’ for environment to draw attention to the serious problems of environmental degradation affecting the entire planet).

The big question is: How are we going to keep our students away from such visions? To achieve that, we must be aware that certain common practices and attitudes encourage distorted visions of science.

1.5. The STS (science-technology-society) approach

When both teachers and pupils are asked what may be the cause of negative attitudes and disinterest towards science and its study, a very general answer is the disconnect between the science being taught and the environment, that is, the absence of STSE (science-technology-society-environment) interactions. If a person does not see the influence that science has in all areas of their life they will not give science the importance it deserves.

The objectives of the STSE approaches are to ensure that pupils understand more about science, and about what science is and its role in society, with the discussion of social, environmental, ethical, political, economic, technological aspects and the interactions that frame scientific development. The STSE approaches are an attempt to integrate Miller’s dimensions for scientific literacy.

STSE interactions break with the decontextualised visions of science and scientific activity (developed in the previous section) to which, unfortunately, teaching sometimes contributes with an unproblematic presentation of knowledge that ignores the social, historical, and ethical aspects that frame scientific development.

This commitment to STSE education is also supported by the Sustainable Development Goals (SDGs) which were preceded by the 'Decade of Education for Sustainable Development' between 2005 and 2014. These are 17 global goals adopted by world leaders in September 2015 and many of which relate to relate to science and environmental education, such as number 13 (action for climate), 14 (underwater life) or 15 (life on land). Also noteworthy is number 4 'Quality Education' which refers to the need for all students to acquire the knowledge and skills necessary to promote sustainable development. Therefore, it is necessary for STSE education to be considered given the serious current socio-environmental crisis.

1.6. The role of teachers

To be able to transmit a correct vision of science, scientific knowledge, and the values that it holds, an educator must possess:

a) Knowledge of science (scientific concepts and procedures). This includes knowing the basic concepts and common scientific terms and using them appropriately in the appropriate contexts.

b) Knowledge about science so that we do not transmit a distorted image of scientific activity, nor do we make science a different knowledge (art or revelation).

c) Scientific knowledge.

d) Skills for professional development, so that we can adapt our skills to the development and evolution of society for many years.

e) Abilities to interact with the students and manage the classroom and the relationship between the classroom and the social environment. In particular, when addressing the diversity of the classroom and managing resources for special needs.

Pedagogical content knowledge implies, at least:

1.- Know and value the **curriculum** and the educative role of each topic.

2.- Formulate **objectives** and competences to develop in each topic.

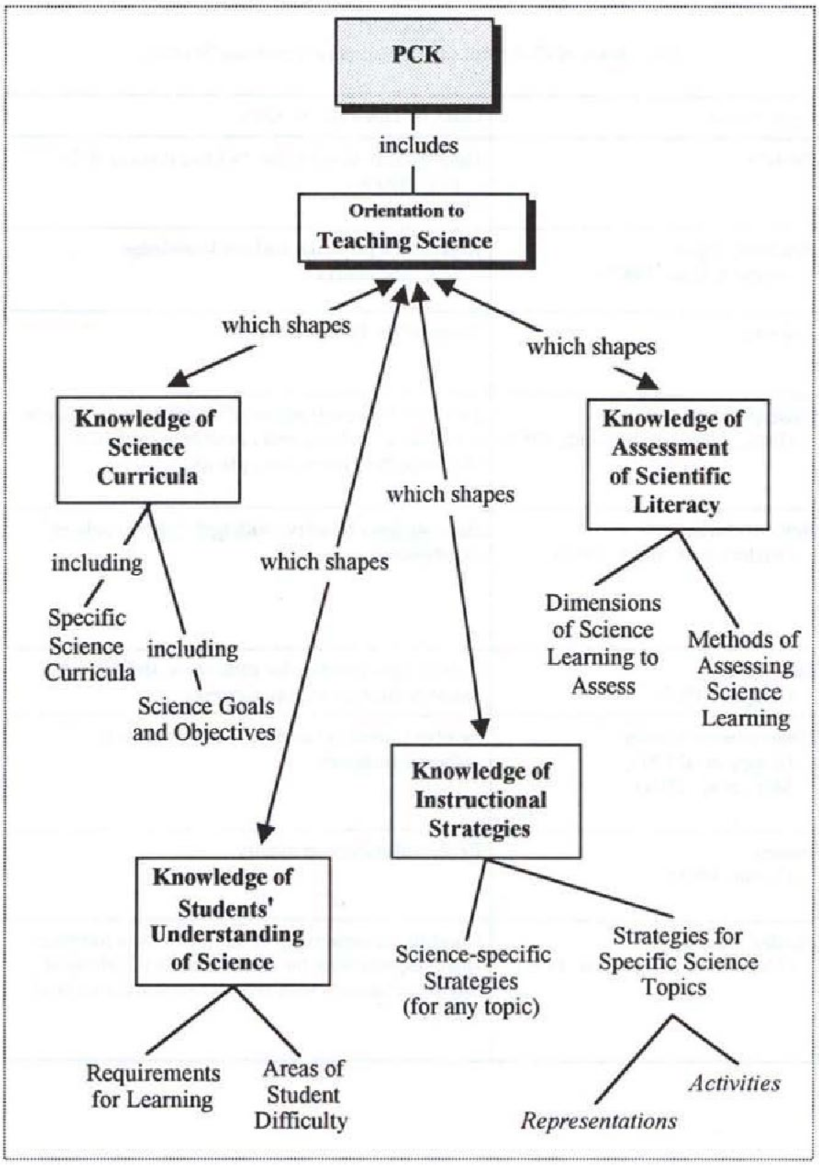
3.- Understand any **learning difficulties** around those topics.

4.- Understand the **teaching difficulties**.

5.- Know how to select a **methodology**, design and implement **learning activities** to achieve the formulated objectives: manage any needed materials, interactions between pupils and pupil-teacher, stimulating interventions, reasoning, questions, and correcting mistakes

6.- Understand how to **evaluate** the objectives and the degree of development.

A conceptual map of Pedagogical Content Knowledge (PCK) as described by Magnusson et al. (1999) is found below:



1.7. What science to teach

Given that science includes many different disciplines, we could ask ourselves what scientific knowledge should be common to citizens and in which contents we should focus our attention in education. This question, like many others in education, has a difficult answer. There are continuous debates on this question and fortunately there have been useful contributions. For example, researcher Wynne Harlen and a group of prestigious colleagues (Derek Bell, Rosa Devés, Hubert Dyasi, Guillermo Fernández de la Garza, Pierre Léna, Robin Millar, Michael Reiss, Patricia Rowell, and Wei Yu) recently arrived at an agreement on ‘the great ideas’ that science education should transmit to every citizen. Some of these ideas are ‘about science’ and others are ‘of science’.

A summary of these ideas is included below. They are called the **fourteen big ideas in science** (Harlen, 2010) and can be divided between ideas **of** science and ideas **about** science.

Ideas of science
1. All material in the universe is made of very small particles.
2. Objects can affect other objects at a distance.
3. Changing the movement of an object requires a net force to be acting on it.
4. The total amount of energy in the universe is always the same but energy can be transformed when things change or are made to happen.
5. The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.
6. The solar system is a very small part of one of millions of galaxies in the universe.
7. Organisms are organised on a cellular basis.
8. Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.
9. Genetic information is passed down from one generation of organisms to another.
10. The diversity of organisms, living and extinct, is the result of evolution.
Ideas about science
11. Science assumes that for every effect there is one or more causes.
12. Scientific explanations, theories, and models are those that best fit the facts known at a particular time.
13. The knowledge produced by science is used in some technologies to create products to serve human ends.
14. Applications of science often have ethical, social, economic, and political implications.

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CHAPTER 2: CHILDREN’S LEARNING AND TEACHING MATERIALS

2.1. Main theories about learning

Learning can be defined as a permanent change in the configuration of the mind. It includes aspects such as the automation of actions, memorisation, reasoning, and comprehension. It affects everything human that is not absolutely determined by genetics. You can learn to be happy or unhappy, have a great memory, pay attention, concentrate, control your own learning, and so on.

Learning can be shown in many different activities: knowing how to do something (actions), reciting by heart, capturing the main ideas from broad information, answering questions (literal and inferential), solving problems of all kinds, making summaries, applying in different contexts what has already been learnt, and perform automatic actions.

Conductist theorists left the mind out of their models because they could not control its content. The main idea is to provoke learning through changes in the environment, and to associate these changes with (observable) behaviour. **Skinner**, with his operant conditioning model, contributed to teaching the use of reinforcement to increase the probability of preferred behaviour being repeated. This model has a good field of application in learning where training (for example, habits) or indoctrination (morals and ethics with reinforcements and punishments) prevails as pupils cannot reason or make decisions freely due to immaturity. An important part of normal human education is based on, or begins with, training and indoctrination.

Unsatisfactory results of conductist investigations led to the recovery of the idea of the mind in learning studies. **Piaget** studied the development of mental capacities (the development of the mind). He based his study on the idea that the key to cognitive development is the development of the logical functions of the mind, which is central to scientific knowledge. These functions are associated with a set of mental operations such as: identification; conservation; ordination; association, classification, assembly (hierarchisation), inversion, generalisation, and exclusion. Many of his studies were carried out using simple scientific artifacts and so his discoveries are especially interesting for the teaching of school science. He postulated different evolutionary stages with different characteristics. For school age children, we find *pre-operative*, *concrete* and *formal operation*s. You have to know how to associate a child’s behaviour with their Piagetian stage in specific cases to know what they can be expected to understand and what not.

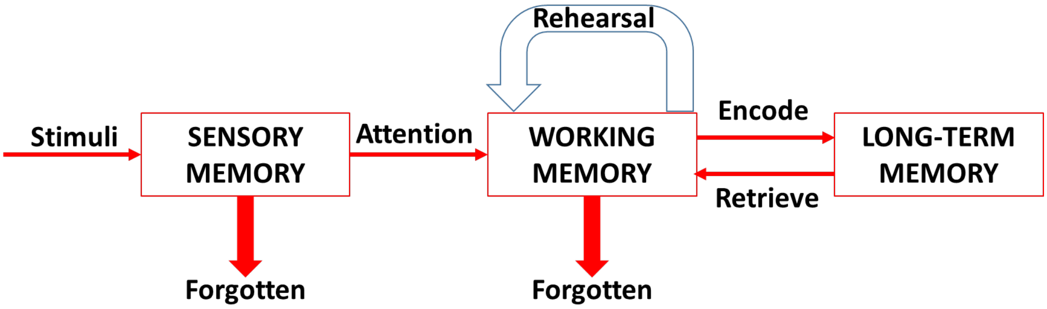
Ausubel proposed the theory of meaningful learning, as opposed to rote learning. This emphasises the prior knowledge of each student because meaningful learning involves relating the learning material with what is known. The cognitive structure that already exists in the mind of the learner (concepts and relationships between them, examples, situations, etc.) completely conditions the meaning of what is being learned. If this structure is not addressed, teaching can fail no matter how well it is organised and sequenced – or even if sophisticated teaching strategies are used. You must study very well the prior knowledge for each subject being taught.

Bruner proposes three phases for how children learn: *enactive*, *iconic,* and *symbolic*. He is convinced that content can be worked on at any age if it is adapted. A spiral (as opposed to the linear) curriculum is proposed by which the contents are retaken at different times, but with progressively greater depth. Bruner also encourages learning by discovery as an alternative to learning by rote and repetition of already developed knowledge.

Vygotsky promotes a causality that seems the opposite of Piaget's approach by stating that children's cognitive development has its origin in social interaction (intervened by language) and not the other way around. Thus, genetics does not impose limitations and determine the rate of progression, and it is poverty or wealth in social and linguistic interactions that is responsible for faster or slower cognitive progress. Learning consists of the internalisation of processes that occur in interactions between people. That is why the tasks of cooperation and help from adults towards children are important. Children learn while expressing their ideas, by discussing and confronting their opinions – but also by imitating adults. Guiding and demonstrations stimulate the internal development processes and enable the child to perform the tasks individually. This author proposes the existence of the zone of proximal development, that is, the learning that the child can carry out without explicit help, based on what they have already learnt and their strategies. The school tasks proposed to the children must be located in the ZPD of each child (the problem is knowing the limits before proposing such activities).

Piaget's work explains the mechanisms by which children develop their cognitive structures and their conceptions about a phenomenon based on their relationship with the natural environment. According to Piaget, social interaction only plays a role in learning when the intellectual structures formed in the interaction with the physical world already exist, while according to Vygotsky, social interaction is what allows the development of cognitive structures that later allow the child to act on and individually interpret natural phenomena. That is why for Vygotsky, the understanding of the physical world is strongly influenced by social categories that are internalised in a certain social and cultural context. For him, as for Bruner, knowledge and human thought are basically cultural and thus most of the learning is a community activity of sharing culture.

The arrival of computers and artificial intelligence gave rise to the **information processing theory**: a simple model of how the human mind works is proposed based on the architecture of a computer. Components such as long-term memory or working memory are currently considered when explaining learning outcomes. Both memories transfer information from one to the other. Long-term memorisation is known to improve with repetition (better 10 sessions of 10 min than 2 sessions of 50 min). Indexed information can be stored and the better the index, the easier it will be to retrieve it. In working memory, information is ‘processed’: it is made conscious, understood, reasoned, details are suppressed, it is generalised, and so on. It is very important to remember that in working memory there is only limited room for information (between 5 and 9 units or chunks of information) and this has been repeatedly proven following Miller's first work in 1956. Experts are capable of handling large chunks, while novices handle elementary and simple chunks. Many of the obstacles students face stem from their limitations in working memory (which can also be made more efficient). A schematic of this model is shown below:



2.2.1. The constructivist conception of learning

In a schematic way we can say that when traditional teaching fails, teaching by discovery appears (based on Bruner's ideas). Discovery can also fail and constructivism appears (consideration of genetic epistemology; importance of previous ideas; responsibility of each apprentice for building their own knowledge). The latter contains a variety of proposals, such as guided discovery, inquiry learning, or conceptual change learning.

Constructivism is a philosophy of learning founded on the premise that humans construct their own understanding of the world we live in as a product of our experiences. Each of us generates our own mental rules and models that we use to make sense of our experiences. Learning, therefore, is simply the process of adjusting our mental models to accommodate new experiences. However, knowledge is shared. Therefore, individual and idiosyncratic constructions must be shared and agreed with other people. Hence the importance of cooperative learning.

According to constructivism, knowledge is not the result of a mere copy of a pre-existing reality. Knowledge is the result of a dynamic and interactive process through which external information is interpreted and re-interpreted by the mind, progressively building explanatory models that are increasingly complex and powerful. This means that we know reality through the models we build to explain it, and that these models are always susceptible to being improved or changed. We should note that the mental models that we build (internal) are NOT our own (external) reality.

The constructivist paradigm has given rise to a critical revision of the teaching models by transmission of developed knowledge and independent discovery by children. Furthermore, constructivism has given rise to alternative teaching models, such as cognitive conflict and conceptual change, or teaching by research (conceptual and methodological change).

It is important to be aware of the fundamental differences between three approaches or understandings of teaching: 1) learning by transmission of developed knowledge; 2) learning by discovery; and 3) constructivist learning.

2.2.2. Some concrete proposals for constructivist-inspired teaching

Alternative ideas and conceptual errors about science for children prevent an understanding of what they are taught. This has given rise to the model of learning by conceptual change (Posner et al., 1982). Its epistemological roots are reminiscent of the paradigm shifts indicated by Thomas Kuhn in the history of science. An instruction aimed to achieve a ‘paradigm shift’ in a learner’s understanding of the world is proposed. To do so, the following four conditions must be present:

a) *Dissatisfaction* with the relationship between one's own ideas and the explanations given by others. The student can be brought into a situation of cognitive conflict in which a contradiction or an irresolvable inconsistency with their own ideas is detected.

b) A new conception *intelligible* to the subject must be presented. The individual will contemplate the possibility of acquiring new conceptions if they have meaning and significance. The new conception will not be capable of replacing the less effective old conceptions (it will not generate conceptual change) if it is not understood.

c) The new conception must be initially *plausible*. It must be conceived by the subjects as a correct conception, which allows them to explain reality in a truthful way. The new conception must solve the problems that the previous conceptions did not solve and it must be consistent with other well-established beliefs of the subjects.

d) Finally, the new conception must be *fruitful*. It must promote the possibility of a profitable research programme or, similarly, be an instrument with explanatory power for the future and suggest new approaches to new phenomena, new paths for inquiry, and new paths for the development of thought.

The **inquiry learning** model assumes that students will learn science better if they build knowledge in a manner similar to scientists – through active inquiry. Naturally, it should be an investigation directed and supervised by a teacher who must provide help when facing obstacles (thus progressing faster than scientists as someone already knows how to solve the problem). The learning method must therefore be a simplification of the ‘scientific method’ (suitably adapted and never conceived as a series of predetermined steps that lead to success). A consequence of this approach is that the methodology must be careful, rigorous, and very controlled – and not superficial like approaches used in everyday life outside the scope of science. Therefore, a ‘methodological change’ and not just a conceptual change is required to work in this way, something that Gil and Carrascosa (1986) already discussed. Another consequence is the importance of cooperative learning, where children collaborate and agree on actions and meanings, knowledge validation, etc. A third consequence is that the history of science can be used to help students be inspired by the way humanity managed to move beyond false or very limited ideas.

The learning by experimentation model has given rise to the **inquiry learning model** whose bases are similar to the previous one, although the *modus operandi* is being developed somewhat further (but not without implementation difficulties). In the next chapter we will deal further with this model.

Both these models, conceptual change and learning by experimentation, are attractive although they require much more time than is available in the classroom. They require a very large development of cognitive and meta-cognitive capacities from pupils, with the aggravation of a prior subject knowledge that is still small (in contrast to that of real scientists). They also demand from teachers a firm subject knowledge and complex teaching skills (such as knowing how to generate cognitive conflict, formulating understandable and interesting questions that prompt an investigation, conduct investigations, and manage the media). Ultimately, no model is a *panacea* or solves all learning problems quickly, they all require great preparation, effort, and patience.

At the same time, the advances in the knowledge of the limitations and possibilities of our mind (cognitive and educational psychology) are explaining many of the detected learning obstacles and developing models for the mind that enable us to design instructions adapted to these features and limitations. In this type of research, progress is slow, as in science in general.

2.2. Characteristics and origin of children's ideas

Children arrive in classrooms with their own ideas about the world around them. Their characteristics are as follows:

- These ideas are 'functional' since these ideas have allowed the children to interpret what happens around them, within the limits of their cognitive development and their needs.
- These ideas are not incoherent, within the pragmatic and unsystematic logic with which they habitually move in the world.
- These children's ideas are often very similar to the ones that humanity has defended in the past.
- However, very often, these ideas do not coincide with those accepted by science. They lose their coherence and their explanatory power when they are subjected to tests in controlled tasks. Inconsistencies, contradictions, and limitations then appear.
- These ideas are difficult to correct and replace. They can have great internal cohesion and constitute authentic explanatory schemes.

The non-consideration of this ‘prior knowledge’ leads to failures in the understanding of school science and, therefore, in the ineffectiveness of teaching. The alternative ideas of the children are constituted in authentic alternative conceptual schemes that probably originate in:

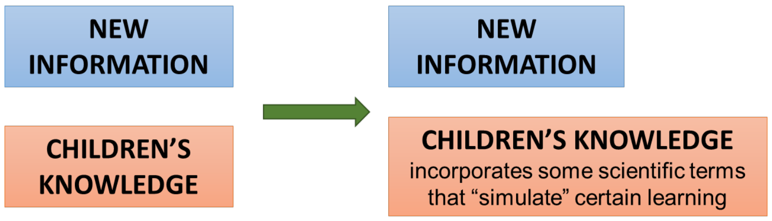
a) Sensory perceptions and reasoning limitations. Their tendency is to base their reasoning only on characteristics perceptible with the senses. Our brain has evolved to perceive signals from the outside world and react to them; therefore, most early-childhood concepts are formed from sensory inputs (that may or may not be defined with language). The pre-operational period described by Piaget is characterised by the lack of separation of the ‘I’ (own acts and the will) and what happens in the world. This means that they interpret reality based on their own egocentric sensations. These egocentric sensations mostly come from concepts (or proto-concepts or notions) formed from the senses. However, in the periods of ‘specific operations’ and even ‘formal operations’ conceptual errors not corrected at the time are also detected.

b) Social interaction. Children interact with adults through languages. Informal language contains many errors and inaccuracies, and, in this way, misleading or even false ideas are transmitted. For example, the word ‘force’ in everyday life differs greatly from the Newtonian scientific concept. (Attention: formal and non-formal adult educators can pass on misconceptions to children when adults unknowingly share such misconceptions. Could this be happening in science?)

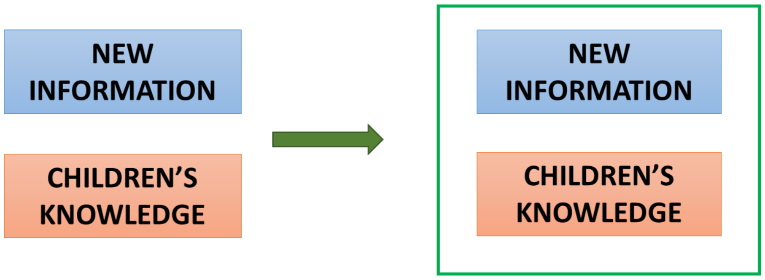
c) The need to apply what has been learnt in one context to other new contexts (transfer). For example, if a child has learned that the closer one gets to a stove the hotter they feel, it will not be surprising if they associate summer with the fact that the Earth is closer to the Sun.

In this context, the possible results of a learning-teaching process are:

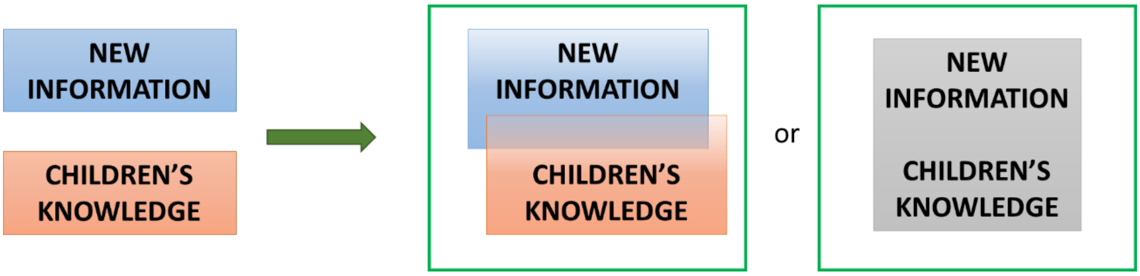
1) New information is not incorporated



2) New information is incorporated but remains compartmentalised



3) Previous ideas are modified (partially or totally) by interacting with new information



2.2.1. Teacher's role in helping pupils develop their ideas

To ensure that the teaching-learning process is optimal and eradicate erroneous ideas, the teacher must:

- Help pupils to *test their ideas*: make clear the rule that all ideas must be tested.

- *Expand the experience of pupils*: through class exhibitions, photographs, and posters in the classroom, information books, out of the classroom activities, etc.

- *Use scientific terms*: introducing the terms appropriately (you must discover what meanings pupils give them *a priori*)

- *Provide alternative and more scientific ideas*. Without destroying pupil confidence in their own way of thinking and reasoning. Scientific ideas should be introduced as alternative ideas worth considering and tested against the available evidence.

- Help pupils to review *previous experiences in relation to new ideas*: so that there are no residues of old ideas that would continue to be used to explain previous experiences. It is convenient to be very explicit and ask 'how have your ideas about ... changed?'

Some possible strategies to help pupils to develop their ideas are listed in the following table:

Origin of the children's idea	**Strategy**
Derived from their limited experience	Expand experience to challenge their childhood ideas: wood that doesn't float; hear sounds through water and solid materials; light and heavy objects falling at the same time
Based on limited observations	Review the investigation carried out; focus on the change process, not just the initial and final condition, which may lead to a different interpretation of the observation.
Centred in one characteristic, and ignoring others	Ask the pupils to keep thinking: '*Something else?*'
Consequence of a wrong reasoning (non-scientific)	Help pupils test their ideas in a more rigorously way and use all the evidence to reach a conclusion

Linked to a particular context	Encourage pupils to apply an idea in a different but related context, to see if it still 'works': '*Can the idea that water condenses in the air explain the moisture in cold cans taken out of the fridge?*'

2.3. Children's ideas about the natural world

Children's ideas about the natural world have been studied extensively for 25 years. The amount of information accumulated is great, but fortunately very useful compilations have been written. One highly recommended book for professional teachers is: *Las ideas «científicas» de los alumnos y alumnas de Primaria: tareas, dibujos y textos.* Rosa Martín del Pozo (coord., 2013). It is available online at: <https://www.ucm.es/data/cont/docs/153-2013-12-16-libro%20completo%5Bsmallpdf.com%5D.pdf>.

2.3.1. Children's alternative ideas about Earth, Sun and Moon

Planet shape

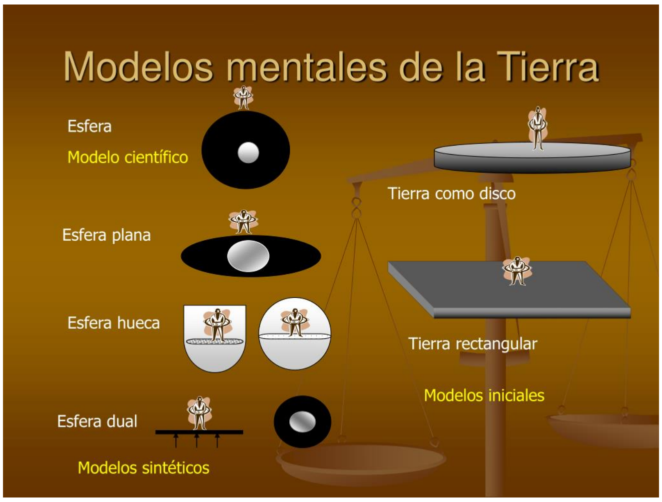
Children start from a concept of a flat Earth and a space limited below by the Earth itself and above by the sky that is seen as parallel to the ground. The objects all fall in straight parallel lines. Analysing the research on the area, four models of the shape of the Earth as seen by children have been detected:

1. A rectangular Earth – with an end from which you can fall.

2. Earth as a disc. Like the rectangular Earth but with a circular shape.

3. Earth as a hollow sphere with people living inside in a flat section.

4. A double Earth. There are two independent Earths, one is spherical and is situated in the sky and the other is flat and where people live.



Gravity

The concept takes time to clarify. Young children use their body schema (egocentricity) to describe what will happen when a stone is dropped in Australia and they believe that things will be 'upside down' in the antipodes. The up / down concept is universal, and not relative. This egocentric model evolves towards another in which things fall to the surface of the Earth and there they stop. Finally, when they mature they accept that objects would fall to the centre of the planet.

Movement of Earth, Sun, and Moon through outer space

Sometimes pupils say that the moon and the sun remain static while the Earth moves. When asked to describe a specific phenomenon with spheres (for example, the day and night cycle), the answers change and they say that they move up-down or left-right. As their conceptual development expands, children begin to handle orbital motion.

Day and night

If they think that the Earth is flat, supported by rocks, and is static, there are two options:

- Those who believe that the sun is static and therefore believe that the sun turns off or is hidden by clouds.
- Those who conceive that the sun moves and therefore believe that the sun hides behind the mountains or that it simply disappears.

If they believe that the Earth is spherical and not static, there are also two options:

- Those who believe that the sun moves and therefore affirm that it goes to the other side of the Earth during its movement.
- Those who think that the sun moves and therefore affirm that it goes to the other side of the hard Earth. Those who conceive the sun as a static star and therefore explain day and night by saying that it is the Earth that moves around the sun or that the Earth is positioning itself above and below the sun.

As we can see, the movement of the sun and the moon cannot be related to 'external to Earth' models (such as those drawn on the blackboard, from the point of view of an external astronaut) until the 'concrete operations' are very advanced. Or even in the phase of 'formal operations' (it is a hypothetical point of view because we are not in a position to place ourselves in it).

Seasons

Understanding seasons is very difficult until the end of primary school. Children mistakenly think that it is hotter in summer because the Earth is closer to the sun. To understand why it is hotter in summer than in winter, it is necessary to understand that radiation depends on the angle of the sun's rays. They must be able to combine the translation of the Earth with the constant inclination of the North-South axis.

Moon phases

These are usually explained by animism or artificialism. Later, they say that the Earth casts a shadow on the moon (confusion between eclipse and phases).

Summary of alternative ideas about Sun, Earth, Moon, and the Universe

1. The Earth is a flat surface and there is air only above.
2.-The Earth is supported or sustained by something in space.
3. The Earth is like a round cake (like a disk), and the sea surrounds it.
4. We live in the flat part of a hemisphere.
5. There is a universal up-down direction, defined by gravity, which is the same on all Earth and in all space. Verticality is the same always, and it is ‘our’ verticality.
6. Gravity does not exist if there is no air.
7. The Sun rises exactly in the East and sets exactly in the West every day.
8. The seasons of the year occur because of the change in distance between the Sun and the Earth (summer→ more heat → shorter distance from the Sun)
9. Night occurs when the Sun goes to sleep, or goes out, or is hidden by clouds, the Moon, or mountains.
10. The Moon only rises at night.
11. The phases of the Moon are produced because of shadows projected on its surface by other objects, in particular, by the Earth.
12. We always see the same face of the Moon because this satellite does not have a self-rotation.
13. Astrology can predict the future of humans.
14. All stars are at same distance from the Earth.
15. Meteorites are falling stars.

2.3.2. Alternative children’s ideas about motion and forces

Alternative conceptual schemes on this subject are deeply ingrained and are difficult to eradicate. Children mistakenly associate force with ‘motion’ (with speed), and not with ‘changes in motion’ (with acceleration). The most important cause is the non-perception of the forces that are exerted by other inanimate bodies, especially the frictional forces that always exist around us (but not in space!). Childhood egocentrism selects the perception of the forces that originate from one's own actions (or those of other people, or those of other animals). Animism and the inability to separate one’s own will from the outside prevent paying attention to the forces produced by inanimate external agents (such as the atmosphere or the ground). The result is that children conceptualise that ‘bodies that move stop if they are not pushed continuously', instead of conceptualising that 'bodies that move stop, precisely, because friction forces act on them'.

By not conceiving the 'invisible' forces exerted by bodies other than the child itself, other people or animals, children cannot easily understand the scientific conception (explained by Newton) which is summarised as follows:

> The natural state of bodies is movement. When no force acts on a body, it will move with a constant speed (in speed and direction): law of inertia. Force is the manifestation of the interaction between any two or more bodies, living or inert, solid, liquid or gas. When a force acts on a body, the effect is to accelerate it (change its speed in quantity, or in direction, or both). The acceleration of a body is the joint consequence of the forces acting on it, and is directly proportional to the resulting force applied. Velocity does not need to have the same direction of the force, but acceleration does. When two bodies interact with each other, whatever they are, the force of one on the other is of the same magnitude, but opposite to that exerted by the second on the first (action-reaction law).

But children's ideas of motion and force often resemble the following ones:

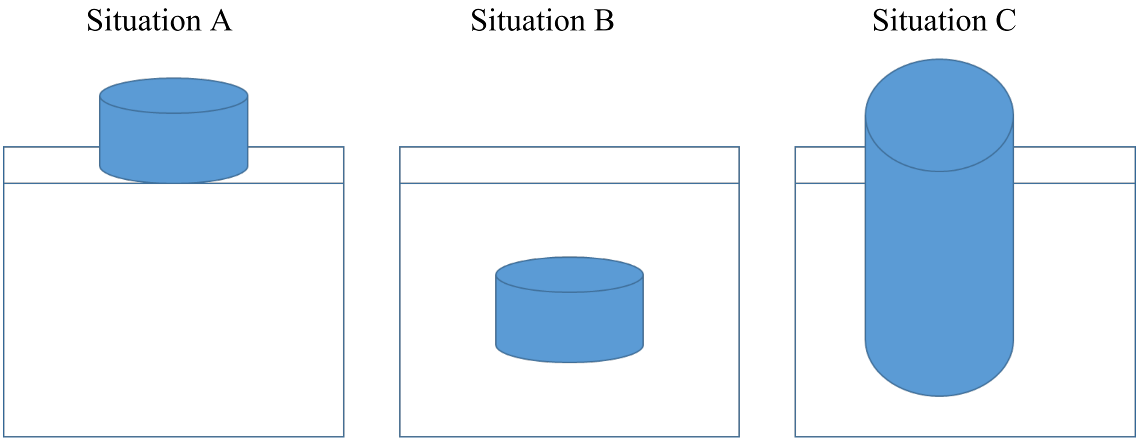
Summary of alternative ideas about motion and forces:

1. The natural state of objects is rest.
2. Forces are produced only by living or animated beings to move or deform objects.
3. If you want a body to move, you must apply a force on it. If you stop applying force, the body stops.
4. The speed of a body is directly proportional to the force applied in the direction of motion.
5. Constant motion requires a constant force applied continuously. If a body moves in a certain direction, it is because a force must be acting in that same direction.
6. If a force acts on a body in a certain direction, then the body will necessarily move in that same direction.
7. Forces are properties of objects: bodies have force when they move, but that force ends when it stops (force / kinetic energy confusion).
8. Friction always opposes and disturbs movement. Therefore, you always want to eliminate friction.
9. If two bodies collide, the larger or heavier one makes more force on the smaller one than the other way around.
10. Work is any activity that requires effort and is tiring; what you get paid for.
11. Machines do more work than people. (Wrong: they do it by applying less force, or they do it in less time).
12. Power is the same as work or force.

2.3.3. Alternative children's ideas about buoyancy

Meaning of buoyancy of a body

Pupils (we will always refer to tests carried out with primary school pupils) are often confused about what they consider to be floating and what is not, that is, which part of the object should be submerged, and which not. If we look at the diagram below, for most pupils, situation A with 'no part submerged' (for example, water striders) is correct. In situation B, since the object is completely submerged, although in suspension (for example, a submarine or a fish) they consider that it does not float. In situation C, in which one part is submerged and another is not (for example, an iceberg) they claim that one part floats and another part does not.



Situation A Situation B Situation C

The causes of buoyancy

Most students explain the reasons for floating for each object in isolation, constantly changing their minds according to the object in question, but they are unable to give a general law that defines the behaviour of all of them. For example, for most pupils, a cork always floats and a metal object never floats, whatever the shape, size, volume, or density of each submerged object or the liquid in which it is submerged. They fix their attention on properties of the body that is introduced into a liquid, but not on the liquid itself (passive object). However, in some cases pupils state that the amount of liquid affects buoyancy (if there is little depth the liquid cannot support the solid body).

Typical evolution with age:

- From 7 to 10 years: 'objects float if they are light'

- From 10 to 12 years: 'objects float if they are light for their size'

- From 14 years on: 'objects float depending on their density'

At the end of primary school, students begin to understand the principle of buoyancy and although they do not verbalise the word 'density' they are already able to understand that it depends on the relationship between two variables. When they say 'light for its size' they relate mass and volume and not a single variable ‘light’ (which depends only on its mass).

The real explanation for the buoyancy phenomenon is found in **Archimedes' principle**: ‘the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces’. Floating depends, therefore, on the relationship between the average density of two bodies, the one to be submerged, and the liquid in which it is submerged. Since density is a relation between mass and volume, Archimedes' principle implies a ‘relation between relations’ which, according to Piaget, cannot be conceived until the ‘formal operation’ stage.

2.3.4. Alternative children’s ideas about matter: solids, liquids, and gases

Concept of matter

Pupils are capable of separating matter from other non-material entities from an early age, although they are unable to concretely define matter with language. They recognise liquids (taking water as a prototypical concept) and solids as matter (although they find it difficult to classify powdered solids as solids and sometimes think they are liquids, or a category in between). However, until the end of primary school or even in secondary school, it is very difficult to conceptualise gases as matter. They are known to exist (it is a domestic and social concept), but they are not associated with ‘material things’. The gas that is in permanent contact with us, the air, is transparent and odourless; therefore, except when there is wind (which collides with the body and becomes noticeable), pupils tend to think that it is not matter. In fact, when pupils contemplate some simple experiences of phase change, they claim that the matter has disappeared (by becoming a gas) and that the weight will now be less. Later, students admit that matter is conserved, but they still think that if 10 mg of water is converted to water vapor, the gas will weigh less than the liquid.

Matter composition

Pupils usually give matter a continuous character, they usually do not accept that between the constituent particles of matter in any state there is a void. They manifest, in fact, ‘horror vacui’ assigning to the void the capacity to ‘suck’ and fill spaces without matter. This is an example of how children’s ideas sometimes reproduce ideas that humanity defended in the past. When they accept the existence of molecules and atoms, they sometimes assign the macroscopic properties of the material to these particles. For example, the expansion or contraction of a material is due to its molecules becoming larger or smaller, copper atoms are reddish in colour, iron atoms are ‘hard’, ice molecules are colder than water molecules, and so on.

Matter properties

The two most characteristic properties of all matter: the fact that it has mass and that it occupies a volume, are not perceived as ever present properties by younger pupils. They believe that mass and volume can disappear. Towards the end of primary school, they already admit that mass must be conserved and that volume is a property of all matter.

Non-material perceptions but with a material support

Nor is it easy to separate matter from non-material perceptions that are associated with a material support such as smell or taste. Young pupils think that sugar when dissolved in water disappears and only ‘its sweetness’ remains in the water. They even claim that the weight of the water is now the same as before adding the sugar. That is, the quality of ‘sweetness’ is conceived as independent of the material support that was the sugar. The same happens when the dissolution of solids in liquids is explained: the youngest children affirm that the solid has ‘disappeared’ and they do not believe that the mass varies.

In state changes children may think that the nature of the substance changes and they tend to transfer the properties of the macroscopic world to the particles (microscopic level). Thus, for pupils, particles melt or change in size.

In chemical changes there are many difficulties in understanding the conservation of reactant particles. Therefore, it is not understood that the masses of the reactants must be the same as the new substances that are formed; they have not assimilated the transformation of some substances into others (by a different regrouping of the atoms). In the specific case of combustion, they think that part of the material is lost in the form of smoke, that the residue in the non-combustible part of the substance or that the new substances or products are a different form of the same substances

2.3.5. Alternative children’s ideas about energy and machines: heat and temperature, light, electricity, magnets, and sound

Heat and temperature

The *concept of heat*, as conceived by current science, is very abstract since it is a form of energy. It has taken humanity centuries to understand. Until the seventeenth century the concept of ‘caloric’ prevailed, which was a supposed substance (material) capable of combining with any other kind of matter and of passing from one object to another. By combining with the caloric, objects increased their volume (logical, since matter was added).

The *concept of temperature* is also very complex to define and understand because it is very abstract. It is recommended to use it in a pragmatic way: temperature is what the thermometer measures.

Heat-temperature confusion. Pupils will arrive at school with a concept of heat closely linked to perception, that is, ‘hot and cold’. Language contributes to creating some confusion: ‘Today is cold’ – in other words, pupils may have a perception of the concept of ‘heat’ little differentiated from that of ‘temperature’: something ‘hot’ (with high temperature) has or gives a lot of ‘heat’ and vice versa.

Conductors and insulators. The everyday use of materials and language facilitates some confusion. For example, many people think that wool ‘gives heat’ (it insulates the body from the outside), or they believe that aluminium foil used for wrapping food ‘keeps heat’ or temperature (when in fact it is a good heat conductor). There are believed to be intrinsically cold bodies (marble) and other intrinsically hot ones (such as wood or wool).

Zero principle of thermodynamics. Few people conceive that if two bodies are in contact for a long time, their temperatures will always equalise. In addition, it can be expressed that what is equal between the two is the heat they possess.

Electricity

Electric current is seen by pupils as a substance that circulates through pipes (the cables). For them, the generator is nothing more than the supplier of the substance that moves through the circuit (we should be careful with the analogy of ‘electrical circuit’ with ‘water pipe’). It is difficult to understand that the charges that circulate belong to the conducting materials themselves (unlike water and pipes) and to assume that the role of the generator is limited to producing an ‘energy gap’ that enables the electrons belonging to the metal of the conductive wire to move in a certain direction (the generator only ‘pushes’ the electrons).

It is not surprising that confusion appears between the concepts of electrical intensity and potential difference (or voltage), or that pupils do not know how to assign the direction of the current between the elements of the circuit and the generator. They also believe that current can reach a light bulb through a single wire (the way water would get to the tap) and they do not understand the need for the ‘loop to be closed’.

Electricity is consumed in the elements of a circuit like the water in taps or in the washing machine. If a light bulb burns out, then they think that it ‘no longer consumes’ and, therefore, the rest of the bulbs will shine more brightly ‘because they now they have more electricity for them’. When one light bulb is behind another, they claim that the second will shine less than the first.

Magnetism

The topic of magnetism is closely associated with their perception during games with magnets and ferromagnetic objects (iron, especially). Today’s pupils do not play with magnets and so their ideas about magnetism are not very developed.

Light

Concept of light. Children cannot conceive light as a signal traveling through space because of the impossibility of perceiving its speed. All optical phenomena are associated with the ‘journey’ of light. Therefore, they will not be able to correctly explain optical phenomena. The first conceptions of light refer rather to ‘illumination’ as perceived by our eyes (remember the sensory origin of many conceptualisation processes): the area observed with brightness, is the area where the light ‘is’ (concept ‘light-state’). The light ‘is’ in the lightbulbs and in the sun. Where there is shadow or darkness, light cannot ‘be’: although we can see the light of a candle in the middle of a dark room, pupils will say that there is no light there.

Sight. Pupils may offer three alternative explanatory schemes for sight: a) light bath. The object and the eye are bathed in ambient light without any interaction between them; b) it is enough that the object is bathed in light to be seen; c) young pupils may think that vision takes place when our eye is directed towards an object and sends out some kind of ‘optical ray’ (egotism that confuses the act of ‘looking’ with ‘seeing’). This egocentric conception is socially supported by comics and stories, even by gestures of social communication (fingers in the shape of a ‘V’ that go from our eyes to another person and indicate that we are looking at them, for example). Even older people have a hard time understanding the role of the eye and the brain in vision. Many believe that the eye projects an image onto the retina, that the optic nerve transfers it to a kind of screen where the brain ‘sees’ it. It is as if there is a small person in the brain.

Mirrors and lenses. The difficulties of conceiving light as a traveling signal conditions the understanding of other phenomena, such as reflection in mirrors or refraction in lenses. An object emits a ‘potential image’ that can travel through space. When that ‘potential image’ reaches a mirror, the image is reversed (collides and returns upside down). When the ‘potential image’ hits a lens, the image can be distorted, or turned around by the lens, and then continues its journey (to the screen or to the eye).

However, children do not show great resistance to learning the correct concept of light (‘light-transmission’ concept) when taught at school (although this does not mean that it is not difficult to master the subject).

Sound

Concept of sound. All children's misconceptions about sound are the result of the non-existence in their conceptual schemes of the concept of ‘mechanical wave’ (disturbance that propagates through a material medium). They believe that sound is something material independent of the medium of propagation. Thus, they may think that sound travels through a vacuum, or that it is ‘destroyed’ when it reaches a solid surface; that sound can push and can be pushed; that it can be contained within something; that it is sensitive to gravity; that it can fall (on the moon you cannot hear anything because as there is no gravity the sound escapes into space).

Propagation. Pupils have a hard time thinking that sound can travel through liquids or solids. When talking about liquids, they think that nothing can be heard under water, and in the case of those who say that it can be heard, they say that it is because the sound travels inside the bubbles.

They also confuse characteristics such as *intensity and tone*. In colloquial language we make mistakes of this kind, such as when we ask someone who speaks very loudly to lower their tone so as not to disturb others, in this case we want the intensity to change and not the tone.

2.4.6. Alternative children's ideas about life sciences

Just to complete the information and make students aware that pupils develop alternative ideas about life science topics, we show here a summary of some of these ideas (although there are many more).

Some alternative ideas about life sciences

1. Living beings are those that move voluntarily. They have a will of their own and human-like desires and behaviour.

2. Plants, fungi, eggs, and seeds are not living things.

3. Every living being has a reason for being, a utility, a destiny in the world, they are here for some reason (in relation to human life).

4. Classifications (conceptualisation) based on irrelevant observations. Example: all living things that live in the sea are fish and breathe water.

5. Plants only eat the sun.

6. Plants are nourished only through their roots with water and dissolved mineral salts.

7. In ecology, microorganisms that play the role of decomposers and recyclers of carbon, nitrogen, water, and minerals are ignored.

8. Daughters inherit most of their characteristics from their mothers, while sons inherit most of their characteristics from their fathers.

9. Only animals have sexual reproduction and not plants.

10. Individuals make efforts to adapt to their environment, and that changes their bodies (acquired characters).

11. Characteristics acquired during life can be inherited.

12. Evolutionary changes in living things occur due to the need for these living things to survive.

13. Evolution has a purpose, a goal that directs it (for example: dolphins developed fins to be able to swim better).

14. Dinosaurs and cavemen lived at the same time (problems with geological time).

15. Health is only the absence of diseases.

16. What you eat grows in you.

17. Incorrect beliefs. For example, during her menstruation, if a woman takes a bath, she can become ill; if mayonnaise is made, it will be ruined; if the plants are watered, they will dry up, etc.

18. Lack of awareness of the environmental impact of every person and of the whole of humanity.

19. Breathing is not part of nutrition.

20. A living being breathes, but not a cell.

2.4. Incorporating all this knowledge to teaching

Stella Vosniadou (2003) in his work *How children learn* summarises what teaching research has found in the last 35 years. This can be applied to work in the classroom to make it more effective and easier. She gives these recommendations (or principles) – and last three are by Vicente Sanjosé:

1. Principle of motivation. Learning is strongly influenced by the motivation of the learner. Teachers, with their behaviour and what they say, can help students to become more motivated learners.

2. Principle of patience. Learning is a complex cognitive activity that cannot be done in a hurry. It requires a lot of time and periods of practice before reaching a minimum level of expertise.

3. Socialising principle. Learning is first and foremost a social activity and therefore it is central to understand that pupils participate in the social life of school.

4. Principle of utility. People learn best when they do activities that are perceived as useful in real life and as culturally relevant.

5. Principle of importance. Learning improves when content is organised around general principles and important explanations, rather than relying on memorisation of isolated facts and procedures.

6. Principle of significance. When the lessons are applied to real life situations, they become more meaningful.

7. Activation principle. Learning requires the pupil to be actively and constructively involved.

8. Constructivist principle. New knowledge is based on knowledge you already have (or against knowledge you already have) and on what is believed.

9. Principle of flexibility. Pupils learn using varied, effective, and flexible strategies that help them understand, reason, memorise, and solve problems.

10. Principle of individual differences. Pupils learn best when their individual differences are considered (and the development of different types of intelligence is taken into account).

11. Metacognitive principle. Pupils must know how to plan and monitor (control) their own learning, learn to set their learning goals, and evaluate their achievement (with bug fixes if necessary).

12. Principle of internal coherence. Pupils must develop the skill to detect and resolve their internal inconsistencies and must learn to restructure prior conceptions when necessary.

13. Principle of cognitive limitation. Every human has a limitation in their ability to manage information. Some complex tasks must be fractioned or simplified to be approached or understood.

14. Principle of the ladder. A tall ladder must be climbed step by step; not by jumping. Not being able to achieve the final objectives of a topic does not imply that learning about that topic is impossible.

15. Principle of repetition and automation. Long-term memorisation of important lessons is best accomplished by repetition. Repetition helps automate processes and relationships between pieces of information (chunks). This frees up cognitive resources for other functions and helps further understanding of the topic.

2.5. The official science curriculum for primary education in Spain

It is suggested that you read the following document: DOGV 7311/07 07 14. Decree 126/2014 of the 28 February. Particularly the part related to natural sciences (from page 18 onwards). Select blocks of contents number 1, 4 and 5, corresponding to ‘Iniciación a la actividad científica’, ‘Materia y energía’ and ‘Objetos y máquinas’ and pay attention to: 1) the progression of content by levels; 2) what is to be evaluated. The evaluation criteria suggest the objectives to be programmed. Of course, not all the objectives must be programmed at the same time in each subject, much less in each learning activity.

2.5.1. Types of content

There are contents (as well as objectives, etc.) of three types: conceptual, procedural, and attitudinal. The characteristics of each according to Vílchez González (2014) are shown in the following table:

CONTENT	LEARNING	ASSESSMENT
CONCEPTUAL Facts, concepts, and principles	**Facts:** rote, reproductive, and isolated. **Concepts:** significant, relation, and integration. **Principles:** understanding of relationships between concepts or facts.	**TO KNOW:** analyse, list, explain, describe, summarise, relate, remember, etc. **ASSESSMENT:** definition, exposure, identification, categorisation, etc.
PROCEDURAL Different actions and strategies to solve objectives or reach goals	Knowledge and use (functionality, use and application) of a set of skills and strategies, methods, rules, skills, or habits to tasks or situations.	**TO KNOW HOW:** to develop, apply, experiment, demonstrate, plan, build, handle, etc. **ASSESSMENT**: the use and practical application in appropriate situations. Integration of actions, generalisation, contextualisation, etc.
ATTITUDINAL Attitudes, values, and norms.	Affective, cognitive, and behavioural component. Willingness to act in a certain socially desirable way.	**TO VALUE:** to behave, respect, tolerate, appreciate, prefer, feel, value, accept, etc. **ASSESSMENT:** systematic observation in its different variants and situations

The **procedural contents** are mainly included in the block of contents on the initiation to scientific activity and are assumed to be relevant to the rest of the contents. Some examples are shown in the following table:

Block 1. Initiation to scientific activity
Experimental approach to some questions Use of different sources of information

Reading of texts related to the area
Use of ICT to look for and select information, simulate processes, and present conclusions
Habits to prevent illnesses and accidents inside the classroom and in the rest of the educational center
Use of different materials according to their safety norms
Individual and group work
Study and work techniques
Development of studying habits
Effort and responsibility
Project planning and reports
Project development

The attitudinal contents try to 'promote curiosity, interest and respect towards oneself and others, towards nature, towards the work of experimental sciences and its social character, and the adoption of an attitude of collaboration in group work'. (RD 126/2014). These can be divided into three types: attitudes towards science; towards learning science; and towards the social implications of science. Some examples for primary education are shown in the following table (source: Liguori and Noste, 2005):

ATTITUDES	CONTEXT OF APPLICATION
Rigour and honesty	Accurate data Experimental results obtained Use of measurement instruments
Respect	To the ideas of others By sharing team tasks
Divergent thinking	Growing curiosity Creativity in solving situations Openness to new ideas, possibilities, experimentations Avoid superstitions Flexibility to form new hypotheses Interest in using various sources of information
Give value to knowledge	Their own body. Health The environment Living beings Natural resources The social impact of science
Critical attitude	Human intervention on natural systems The use of natural resources Diet and consumption of health-related products

	Sexuality and the prevention of sexually transmitted diseases. Contraceptive methods Drug use and other addictions Limitations of science

2.6. Teaching analysis as part of the Pedagogical Content Knowledge

As we have seen in Chapter 1, the professional knowledge that defines a teacher is the Pedagogical Content Knowledge (PCK from now on). This knowledge implies:

1) Defining conceptual, procedural, and attitudinal objectives.

2) Analysing and assessing the school curriculum (concepts, processes, attitudes, and their relationships) and what is the relevance of each topic for educational purposes.

3) Knowing the most common learning difficulties of students and their origin.

4) Anticipating teaching difficulties that may appear for a particular subject within the physical and social context for current pupils.

5) Determining the most appropriate methodology for the proposed objectives and developing and conducting educational activities (also related to the objectives).

6) Evaluating planned objectives in a win-win approach.

An empirical analysis of the structure of the PCK in school sciences reveals the presence of two main factors: one of teaching analysis, and the other of teaching action (Verdugo, Olmos, Solaz & Sanjosé, 2016). The first factor, **teaching analysis**, encompasses the formulation of objectives, judgment on the relevance of the topic and its content, and knowledge of possible learning difficulties of the pupils, and a prediction about the teaching difficulties of that topic. The second factor, **teaching action**, also contains the formulation of objectives (which is the basis of everything), the concretion of methodology and educational activities, and assessment.

This course focuses mainly on the teaching analysis factor that should precede the teaching action. The second factor, teaching action, will be the focus of the following course.

We will learn how to analyse the contents of each science lesson and: a) extract the concepts, procedures, and attitudes, and their relationships that are worth planning; b) anticipate and reduce learning difficulties; c) make decisions about the teaching materials most related to our professional criteria.

2.6.1. Elements and organisation of teaching analysis

Teaching analysis is an effective tool for teachers to enhance critical judgment from a point of view that puts the teaching process at the centre. This tool can be structured on categories to aid critical reflection and decision-making for classroom intervention. The categories are defined by a set of questions that combine the main components of the teaching analysis (objectives, relevance, learning difficulties and teaching difficulties) and the teacher's fields of reflection (the subject and its context, the content and teaching procedures). The categories and questions for teaching analysis are included in the following table:

Objectives	
Subject and context	What is the desirable knowledge for pupils in relation to the subject? How to define simple, feasible, and assessable objectives?
Content and topic	What educational and instructional potential does the content have? What concepts and processes are important? What are the questions that I can ask myself using each concept and process to contextualise, simplify, clarify and deepen its meaning?
Relevance	
Subject and context	What ethical, social, or environmental problems are related to the subject being taught? What are the most relevant social and cultural dimensions related to the topic? What significant potential do these concepts have in relation to the interests and needs of my students?
Content and topic	What are the structuring concepts of the discipline or topic present in the analysed curricular material? What other themes can be related to these concepts to establish links with other thematic fields?
Learning difficulties	
Subject and context	What everyday conceptions are put into play (wrong and correct)? What is their origin? (Cultural, tradition, use of language, sensory, cognitive, inappropriate transfers, etc.)
Content and topic	What conceptions does the student have on this topic? How do pupils conceptualise reality? What implications does this conception have?
Teaching procedures	How can I make those conceptions explicit and make my pupils aware of them? How can they work to modify those conceptions?
Teaching difficulties	

Planned teaching procedures	What is the most appropriate methodological orientation to achieve the proposed objectives? (Verbal transmission, experimental activity, cognitive conflict, etc.) What types of educational activities are most appropriate to acquire these concepts, while overcoming learning difficulties and little if any prior knowledge? (Research, reading, watching educational films, role-playing games, etc.) What forms of work organisation in the classroom could be proposed? Are they relevant and consistent with educational purposes? (Work in small or large groups, or individually or in pairs; teacher-guide, teacher-source, teacher-consultant, etc.).

Please note that teachers are usually subject to legislation and regulations and cannot freely choose the content they teach. However, in practice, the time available, the abilities of the students, and the circumstances force professionals to prioritise and give emphasis to certain parts of the content. This is when it is useful to have developed a good ability to differentiate the most relevant and important topics from the less relevant, secondary, or anecdotic.

In summary, the teaching analysis must ensure that the competent professional knows how to choose the most profitable content for their students (considering their social, historical, geographical, and economic context) and formulate with clarity and simplicity the specific objectives **to help** their education. **Those** objectives must address, among other aspects, overcoming conceptual difficulties and providing sufficient and relevant knowledge for a **current and future** citizen. To decide what is more or less relevant, the professional must know the school curriculum and have a certain basic mastery of the content of the subjects (in this case, of the content in basic sciences).

2.7. Educational objectives (learning outcomes)

a) The objectives must be **simple** and **concrete.**

Higher or more general educational objectives (including instructional ones) are determined by current legislation. However, the generality and breadth of their formulation makes them difficult to handle in the classroom by a teacher. In the classroom, it is necessary to specify objectives as much as possible, so that on a daily basis and despite the number of students, it is possible to monitor whether each of the students achieves the objectives or not. Thus, for example, a formulation (invented for the case) such as the following: ‘respect the environment by valuing its importance for life’ is so general that it is difficult to know what to do to develop it when you are inside a classroom with 25 pupils. However, 'developing the habit of not dirtying the place where you are playing or working' seems much easier to work with a group of pupils and, above all, to continue throughout the course or life.

b) Objectives must be clearly **related to the topic** in question.

We must try to avoid very generic objectives which can be formulated on any subject. However, there will always be a group of 'long-term' objectives which may be present due to their importance and the time they take to develop. Examples of these are attitudinal and behavioural goals

c) Objectives must be **varied.**

As is known, there are several types of objectives that must be considered. Regardless of the taxonomy or typology used, what matters is to think that the greater the variability, the greater the chance that students will learn. Each person develops certain types of intelligence, and it is easier to 'reach' everyone if the objectives (and, therefore, the educational activities that relate to them) are varied. An example of a typology, now classic, is the division between conceptual, procedural, and attitudinal objectives. It is very useful to become accustomed to formulating objectives (concrete and simple) of the three types in any 'lesson' or instructional session, but some can be repeated, since they need time and repeated work to be achieved.

d) Objectives must be **assessable** in a quick and simple manner.

It is important to formulate multiple objectives in each session or in each activity. Focus on the most essential and try to ensure that the evaluation of that part is clear and can be done during the development of the activities (online) and not only at the end or in a specific subsequent test (offline). Many people agree that evaluation should be done on an ongoing basis, but then this is sometimes just 'pretty words' and unfair subjective evaluations are made. The way to make this a reality is to make the objectives few in number and very simple, so that during each session or activity the teachers can really follow progress in each of their pupils through observable indicators

Each objective can have one or more observable indicators. Making a template in the form of a double entry table like the following is very helpful:

	Obj1		**Obj2**		**Obj3**		**Obj4**	
	In1	In2	In1	In2	In3	In1	In1	In2
Pupil 1	*V*	*V*	*V*	*X*	*V*	*V*	*V*	*X*
Pupil 2	*V*	*X*	*V*	*V*	*V*	*V*	*V*	*X*
Pupil 3	*V*	*V*	*V*	*X*	*V*	*V*	*V*	*X*
Pupil 4	*V*	*V*	*V*	*V*	*V*	*X*	*V*	*V*

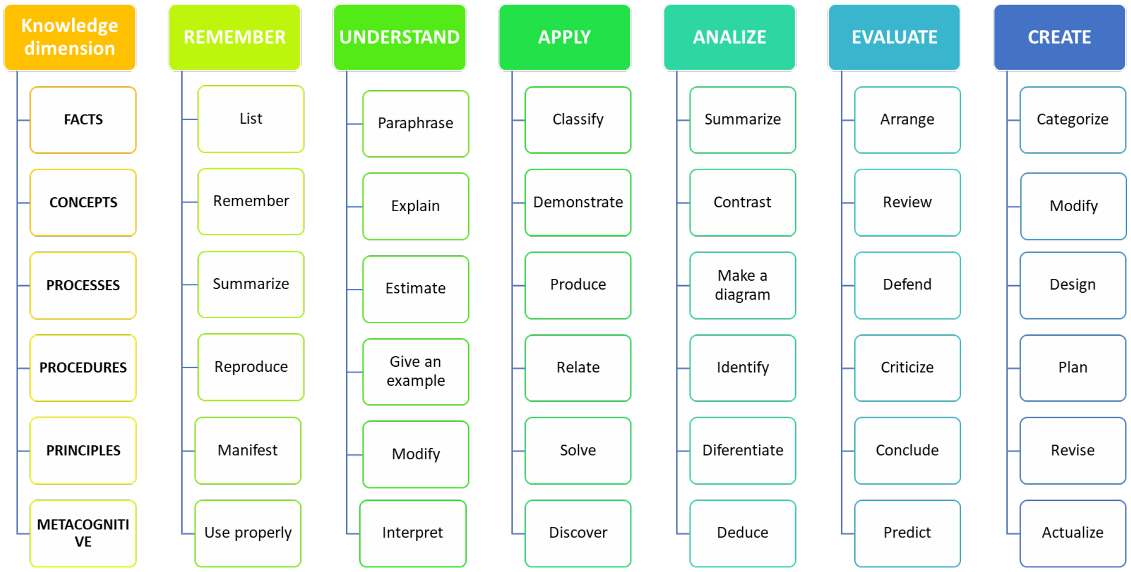
V: reached; *X*: NOT reached

Obj= objective; In= observable indicator.

The next table shows some examples of objectives in different basic science topics:

Examples of objectives in different basic science topics
• Overcome the misconception that plants eat through their roots.
• Understand the concept of density of an object.
• Classify objects in the environment as ‘living beings’ or ‘inert beings’
• Predict whether an object will float or sink in water, and justify that prediction
• Explain why we see the phases of the Moon.
• Describe the behaviour of a pet over several days.
• Know the parts of a plant and its vital function.
• Measure the volume of an irregular solid with the help of a graduated container and water.
• Cooperate in the development of an experimental activity with use and order.
• Communicate in an understandable way the reason, development, and results of an experiment.
• Accept mistakes and the appearance of ‘bad data’ (contrary to expectations) as an opportunity to learn, rather than a reason for frustration.

Let us remember that the BOE, the DOGV, and PISA also show how to evaluate objectives. Care must be taken so that the objectives are varied in their demands to develop different skills (the more the better). Bloom’s taxonomy is a classic proposal that can guide and help us propose tasks with various cognitive demands. A schematic summary of Bloom’s taxonomy can be found below, where the level of complexity grows from left to right:



Knowledge dimension	REMEMBER	UNDERSTAND	APPLY	ANALIZE	EVALUATE	CREATE
FACTS	List	Paraphrase	Classify	Summarize	Arrange	Categorize
CONCEPTS	Remember	Explain	Demonstrate	Contrast	Review	Modify
PROCESSES	Summarize	Estimate	Produce	Make a diagram	Defend	Design
PROCEDURES	Reproduce	Give an example	Relate	Identify	Criticize	Plan
PRINCIPLES	Manifest	Modify	Solve	Diferentiate	Conclude	Revise
METACOGNITIVE	Use properly	Interpret	Discover	Deduce	Predict	Actualize

Note that, in the upper part of this diagram there are **fundamental cognitive skills** for education in science and otherwise. In the left column are the **dimensions of knowledge** that may be affected. This is a source of inspiration that must always be adapted to the educational intentions of the teacher.

Learning activities must always relate to the objectives formulated by the teacher. This means that each activity will be carried out so that one or two objectives (in any case, a few) can be developed (often little by little). Although the same activity could involve many objectives, it must NOT refer to everything that 'could be', but rather to what 'is programmed and can be covered'. In general, you should not cover (evaluate) objectives that have not been previously programmed.

There are other taxonomies that determine the types of learning, graduating their demand, and associating them with tasks, but this one helps to better distribute the activities and to know what can be expected of the pupils.

2.7.1. Scientific competences in educational activities

The objectives to be achieved, specific to the topic in question, are determined after analysing the relevance of the content, and the relationships of importance within it. All the objectives together should help increase the scientific abilities of pupils. Some skills and tasks related to scientific competence are displayed below:

Skills associated with scientific competence and developed through learning tasks
- Ask questions or pose problems about the world (using ways of representing science when possible).
- Recognise when a phenomenon or an event can be explained within the framework of a certain science.
- Identify the relevant magnitudes and parameters in each situation.
- Describe phenomena or events using notions or concepts from science. Mastery (according to level) of abstract languages typical of science.
- Explain phenomena or events using concepts, principles, and laws of science.
- Predict events and phenomena based on causal schemes in science. Predict effects of actions carried out on systems and judge their validity.
- Apply the acquired knowledge in new contexts and situations (recognising limits and conditions).
- Solve problems using (according to level) methods, theories, and concepts of science (include the ability to solve typical science problems).
- Comprehensively use instruments, technologies, and sources of information.
- Correctly measure the value of magnitudes and parameters previously determined (and with the appropriate instruments).
- Interpret the results of the measures taken (link numbers to reality).
- Be aware of anomalous data contradicting predictions. Accept that these data must suppose a revision of the formulated hypotheses.
- Use the acquired knowledge to build new knowledge.

- Make results obtained available to other people in an understandable way.
- Recognise when data contradicts a hypothesis and accept the need to reformulate it.

The competent bodies publish in their official documents the objectives and content to be achieved in each school subject. International studies such as PISA have simplified the variety of objectives that could be proposed and suggest a common scheme that helps to determine specific objectives on any subject. Although PISA is focused on secondary education, its development helps us analyse primary education in the same way.

2.8. Concept maps

Concept maps are simple and practical tools for the representation of knowledge which enable complex conceptual messages to be transmitted clearly and facilitate both learning and teaching. They take the form of hierarchical graphs.

They originate from David Ausubel's learning psychology theories enunciated in the 1960s. Concept maps were developed to understand changes over time in children's knowledge of science. Ausubel's idea is that learning takes place thanks to the assimilation of new concepts and propositions into propositional frames of reference (schemas) already existing in the mind of the learner.

A concept map allows to focus the attention on structuring a topic instead of focusing on specific or ideas. The teacher can use this analysis tool to delve into the hierarchy of concepts, and the important relationships between them. The teacher must prioritise the importance of ideas, from the widest, inclusive or abstract, to the most defined, concrete, and exemplary. In addition, to create a concept map one must understand or work out the existing relationships between all these more general or more specific ideas. Thus, concept maps help structure a topic before tackling the details. As one goes down the map, it will arrive at the specific examples of the topic. If you do not know how to give examples of the transmitted ideas (science or not), then maybe you do not master the subject as much as you should.

The elements that form a concept map are the following:

Concepts: regularity in events or objects that is designated through a term. 'Book', 'mammal' or 'atmosphere' are examples of concepts.

Link words: They are used to link the concepts and to indicate the type of relationship established between them. For example, if we relate the concepts 'age' and 'experience' using the linking words 'provides' or 'modifies', the propositions they generate are similar, but not identical.

Propositions: two or more conceptual terms joined by link words to form a semantic unit. 'The city has an industrial zone' or 'the human being needs oxygen' are examples of propositions.

Examples and images: Sometimes it is useful to include in the base of the conceptual map examples of specific objects or facts that illustrate the origin of the meaning of the concept (the regularity that is represented).

The steps for preparing a conceptual map are as follows:

1) Read the text carefully and underline the main ideas.

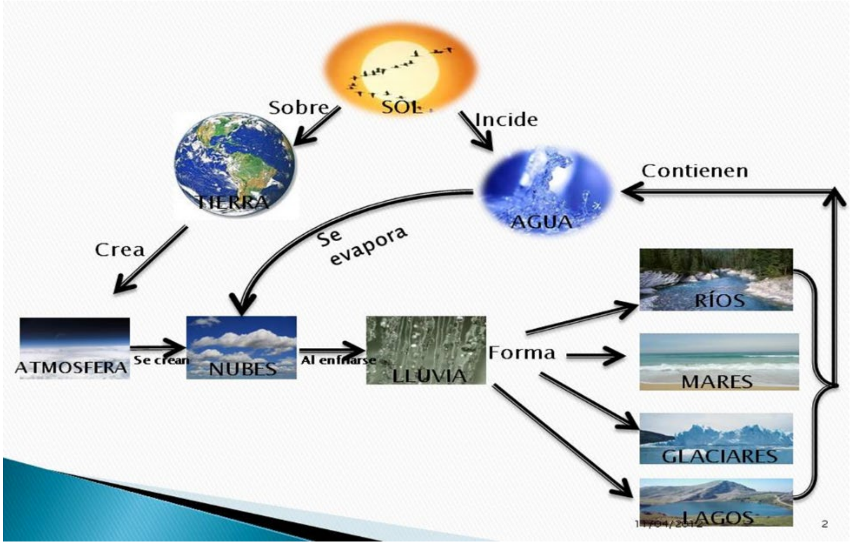
2) Select a small number of concepts or ideas.

3) The concepts are enclosed in a box or an ellipse for a better view.

4) Put the concepts in order of importance; the most important at the top, and the least important at the bottom.

5) Join the concepts by lines and relate them by words that serve as a link.

6) Once finished, it is worthwhile repeating the map to improve its clarity and establish new links or relationships.



Example of a concept map about water cycle

2.9. Types of activities and educational materials in basic sciences

2.9.1. Activities

Once the objectives within a topic have been clarified (which will usually be defined by the current school curriculum), the materials that facilitate the pupils achieving the planned objectives must be provided.

The development of the concepts, the mastery of basic processes typical of science and the understanding of the nature of scientific activity, suggests that an important part of the activities be **manipulative or experimental**. Concepts are always involved in experiments so that processes (such as measuring, predicting, making explanatory guesses, communicating, and asking) are acquired at the same time as concepts.

From a cognitive point of view, the manipulation of reality (although in simplified conditions and limited contexts) facilitates its understanding when compared with symbolic mediators (text, drawings, graphics, photos, etc.). If you are going to study natural reality then why not go directly to nature? Why use texts, diagrams or even images? It seems more appropriate that the processes of symbolisation (abstract) is used after the reality itself has been perceived. Objects and events can be described in terms of everyday life (more concrete and less abstract) and a level of maturational development that allows abstraction (states, phenomena, and laws).

Using this approach improves the image transmitted at school about what is science. This image is very distorted if you only work using textbooks. In science 'knowing how to do something' is as important as 'knowing how to say it' and helps achieve understanding. Manipulating reality aims to obtain answers to previously formulated 'human' questions (hypotheses and predictions) or even to obtain new questions. This is the most exciting and creative activity of a scientist. In simplified situations, we should not deprive pupils of the possibility of feeling like scientists.

Another argument in favour of experimental activities is that if they are developed in small groups, they allow the treatment and monitoring of educational objectives (attitudes, behaviour, collaboration, respect, division of work, order, and responsibility). Purely conceptual activities (typical of reading and 'turning the pages' of a book) are individual and can hardly develop socialisation with all the values involved .

Finally, manipulative activities are much more fun and motivating for pupils. Although fun is not the object of the activities, it is true that such activities stimulate, leave good memories, and promote positive attitudes towards science that can last forever (regardless of whether the person later works in scientific activities or not).

2.9.2. Instructional materials

In general, we can find instructional materials in any format. We must never forget the teacher himself, whose culture, gestures, way of expressing himself and non-verbal language creates, increases or depresses the effort that a student can make (self-concept, interest, time, dedication, illusion, etc.). We can find good textbooks, web materials, apps, and movies, and, above all, reality itself!

In any case, and as we well know, **school textbooks** are a widely used instructional resource. Its components are: a) the text or speech based on a language (natural or abstract); b) such as figures, graphs, drawings, and diagrams; c) the proposed activities around the topic. These components must interact profitably when the student processes this material. For example, the images must be close to the text and complement the textual information; activities must be varied to contribute to the development of different cognitive skills; the text must be very structured and clearly state the main ideas to work on or develop in the activities.

Text and even graphic images are symbols that encode information and it requires a certain number of cognitive resources to decode and even understand what is being explained (simple identifications and descriptions). The images in a film are a more accurate and closer representation of reality and help understanding more than texts.

Professionals should never forget that **reality itself** is the best source of information for learning about reality. The direct observation and manipulation of reality (albeit in controlled and simplified situations) minimises the cognitive effort required to mentally represent objects and events in the world. By freeing cognitive resources, they can be dedicated to the construction of abstract mental representations (concepts and laws of science). The time spent in the preparation of manipulative materials, coming from the pupil's own surrounding reality, is more than compensated with the educational benefits obtained.

The proposed experimental or manipulative activities require materials that are either found in the school laboratory (however, many schools lack such a laboratory) or must be found in the immediate environment of the pupils and their families. In any case, sophisticated, expensive, or hard-to-find materials will have a dissuasive effect for both teachers and the families of pupils. Therefore, it is necessary to ensure that the experimental materials are cheap and accessible. Fortunately, many worthwhile activities can be done with everyday objects.

The exception is some measuring instruments (electronic balances or scales, laboratory and non-medical thermometers, litmus paper, density meters, filter paper, voltmeters, and ammeters, etc.) and graduated or non-graduated vessels that resist large changes in temperature. These utensils must be purchased in specialised stores found in all provincial capitals (and online). You must buy what is necessary, take care of it, use it, and replace what is damaged – but the cost is not usually great.

In addition, you can find specialised educational toy stores that offer very useful items for pupils. This is the case of companies such as Dideco, Abacus, and Eurekakids.

2.9.3. Adapting materials to pupil characteristics

The variety of instructional materials available today enables us to consider adapting them to the individual characteristics of the students. The question is, what do we rely on to know what is best for each person? The concept of 'learning styles' emerged to provide a scientific answer to this question. An easy-to-use model that can help decide instructional materials formats is the VARK model.

For a teacher, it is interesting to know what is the preference in his classroom, that is, the style that is most repeated. It is also very important to know what preferences pupils with difficulties have. Once this is known, the teacher can better choose which materials-tasks to propose to his pupils. Here are some practical suggestions for each learning style:

Teaching strategies for visual style	**Teaching strategies for auditory style (A)**
• written instructions • concept maps • diagrams, models, synoptic tables • computational animations • videos, transparencies, photographs, and illustrations	• verbal instructions • repeat similar sounds • audios, podcasts • debates, discussions, and confrontations • brainstorming • read the same text with different reflections, • guided and commented reading
Teaching strategies for reading / writing style (R) • one-minute briefs • literary compositions, diaries, blogs, and reports • preparation of summaries, reviews, and synthesis of texts • peer review of texts	**Teaching strategies for kinesthetic style (K)** • role play and dramatizations • group dynamics • realistic movies • manipulation of objects to explain phenomena • gestures to accompany oral instructions.

2.9.4. Textbooks

Although science should not be learnt only from books, we cannot ignore their widespread use. A good textbook is a very useful material from which the teacher must know how to extract the best in accordance with the educational goals.

Science texts (even if they are basic) are not easy to understand since they involve concepts that do not belong to the ordinary world of children. Written by adults, they demand from readers an enormous number of inferences that go unnoticed by older readers.

A pupil may not understand some terms, or the language syntax; and they may encounter obstacles in extracting the meaning of certain isolated ideas, or in extracting the main idea from a passage, or in connecting different ideas from the text. Finally, pupils may encounter difficulties when making inferences to link different ideas from the text or to link the ideas in the text with their prior knowledge. All this is aggravated when ideas have an abstract character.

Actions to improve the understandability of a text can focus on different aspects related to the text itself (adequacy, coherence, and cohesion), to the reader (learning goals, prior knowledge, and strategies) and to the tasks proposed because of the study of the text (the tasks influence the goals of the reader and, in turn, this influences the previous knowledge activated and the strategies used). Reducing unnecessary inferences, and facilitating the activation of adequate prior knowledge, can greatly improve a learning material.

A summary of the scientifically based improvements that can be made in an educational text are as follows (Sanjosé, Solaz-Portolés and Vidal-Abarca [1993]):

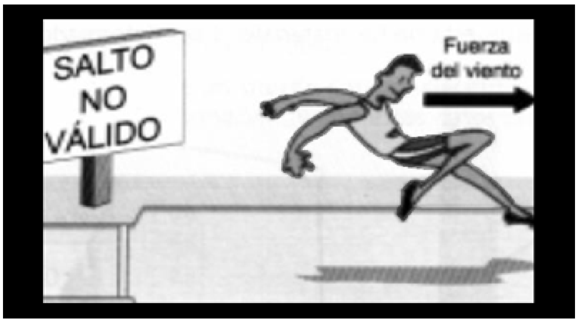
Content
Consider the reader's preconceptions and introduce the concepts from their previous knowledge
Redundancy in presenting and developing important ideas
Provide explanations that relate textual information to the reader's real world
Use analogies
Present the concept of the scientific model and its potentialities, according to the pupil's maturational development
Organisational structure
Underline the conceptual principles by placing them at the beginning of the text, sections, or paragraphs
Start from the best known, simplest, or most familiar ideas
Present the different topics to be discussed in titles, headings, or phrases
Use different paragraphs for different units of information
Cohesion
Reduce unnecessary lexical and syntactic complexity
Establish explicit relationships between ideas in such a way that the textual inferences to be made are reduced
Eliminate ideas irrelevant to the content discussed
Facilitate the union between referrals
Increase connectivity between phrases
Use particles that direct the reader's attention and facilitate inferences during reading
Surface structure
Highlight main ideas using bold or larger type
Use introductory phrases announcing the content, as well as summary phrases
Offer titles and headings that provide more structural information and are well placed
Adjust the linguistic style to the reader
Other features
Include figures to increase textual cohesion and facilitate the construction of mental representations of spatial content
Explain the figures and interconnect them with the text
Simplify and eliminate unnecessarily complex numeric expressions

2.9.5. Graphical elements (drawings, diagrams, pictures, etc.)

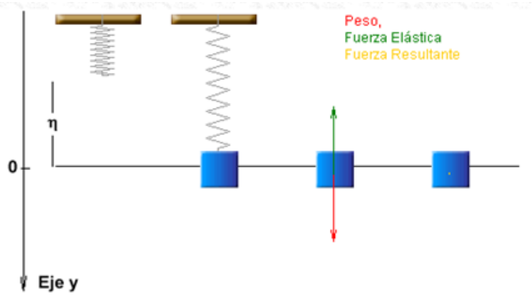
The brain processes images (spatial information) and natural language (verbal information) with different (and sometimes complementary) cognitive resources. The presence of images in textbooks is justified by the possibility of providing spatial information that facilitates the construction of mental models and, therefore, by contributing to a better understanding of the information. This is one of its main missions: to supplement verbal information with spatial information.

In textbooks it is common to find schematic images or figurative-schematic images. Those are images that show an imitation of reality with objects and/or events of a simplified (figurative) reality. In these images a representation of actions is added: invisible, abstract, theoretical (schematic) magnitudes are superimposed to help link theory with reality.

Figurative-schematic image



Schematic image



The second mission of images is, therefore, to help link abstract concepts typical of science with reality (objects and events). For example, simplifying reality to show only the qualities that have theoretical relevance, or showing theoretical magnitudes or entities necessary to understand a fact using arrows, signs, process marks, etc.

It is important to ensure that the images have an appropriate meaning for the students, as well as being ‘nice’. That is why they must be close to the text where the information is mentioned and be complementary to the text, as we have explained. Sometimes it is taken for granted that pupils understand images without problem, but sometimes they cannot relate those images to the information to be transferred.

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CHAPTER 3: SCIENCE PROCESS SKILLS AND INQUIRY LEARNING

3.1. Instructional models in science teaching

The three basic didactic models in science teaching are the transmitting model, the learning by discovery model, and the constructivist model.

a) **Transmitting model**: it consists of the transmission (oral or written) of already developed knowledge from one person to another and assumes that the student is a blank slate (or blank page) that acquires knowledge thanks to the teacher's explanations. In addition, it considers the sciences as a closed body of knowledge that does not change and grows by accumulation. This model presents a series of problems: the oral transmission of knowledge, no matter how clear and orderly it may be, does not ensure its understanding or learning; knowledge is not acquired in an already developed state, but each person remakes it according to their previous knowledge and experiences; science does not grow by accumulation, but theories and models can be modified or abandoned due to the need to solve new questions; knowledge that responds to problems that students have not previously posed is unlikely to be significant.

b) **Learning by discovery model**: it affirms that the best way to learn something is through self-discovery. The conceptual contents lose importance and the importance of the useful procedures for the application of the scientific method (mainly observation and experimentation) is emphasised. It considers that sciences are defined by the general and universal scientific method. However, although this model appeared in response to the failure of the transmitting model, it also has problems: students do not always discover what teachers want them to discover, and empirical evidence often reinforces their previous childhood ideas; contents have a secondary value and students are expected to learn them on their own; it is difficult to plan and direct this kind of teaching if you want to take into account all the interests of the students.

c) **Constructivist model**: it affirms that the learning process consists in the active construction of new knowledge from the learner's previous knowledge. Constructivism considers the learning theory of Piaget, who argues that human beings learn through doing and actively exploring, and the meaningful learning theory of Ausubel, who states that learning is meaningful when it can be related with what the student already knows. In this model, the pupil is responsible for their own learning process and the teacher guides the pupils to build new and meaningful knowledge. In addition, it considers that science is a process of interpretation of reality through models, which are always susceptible to improvement or change. Conceptual contents regain importance because they are considered complementary to scientific procedures. Thus, constructivism has given rise to alternative learning strategies such as learning by conceptual and methodological change, STS (science-technology-society) learning, and inquiry learning.

The main characteristics of these teaching models according to Benarroch (2011) cited in Vílchez González (2014) are shown in the following table:

		Transmission model	**Learning by discovery model**	**Constructivist model**
Fundaments	**Science concept**	Absolute and true science	Empirical science (objectivity in observation)	Paradigmatic science (importance of previous knowledge over observations or research)
	Learning concept	Cognitive structure as an 'empty box'. Learning by hearing	You learn better what you discover on your own through activities	You learn by reconstructing cognitive models. This reconstruction involves physical, symbolic interactions, etc.
	Communicative relationships	None	Not important	Important and varied
Didactic elements	**Objectives**	Remembering content	Learn about scientific processes	Comprehensive student training (concepts, procedures, and attitudes)
	Content	Conceptual	Procedural	Key ideas with great explanatory power approached from the environment
	Methodology	Transmission	Cycles: observation, hypothesis, experimentation, results, inferences, and conclusions	Diagnose problems, criticise experiments, distinguish alternatives, investigate conjectures, search for information.
	Resources	Blackboard and textbook	Laboratory	Varied resources: written, experiential, technological

	Assessment	Final (summative)	Continuous (formative) Final (summative)	Initial (diagnostic) Continuous (formative) Final (summative)
	Teacher's role	Transmitter	Media and resource facilitator	Diagnosis, motivator, guide, researcher in action

The main types of activities that are implemented in science classes are the following (Rivero García et al., 2017):

More frequent classroom activities (50-80% of people)	**Less frequent classroom activities (25-35% of people)**	**Quite rare classroom activities (15-18% of people)**
Reading the textbook in class. Problem solving or exercises. Exposition. Answering questions from the teacher about the lesson. Written work on a topic or activity carried out. Dialogue exhibition.	Expression of pupils' previous ideas. Field trips. Movies or videos. Urban departures. Consulting class library books. Holding meetings. Carrying out projects. Cultivation or maintenance of living things in class. Self-assessment sessions.	Tending a school garden. Constructing objects or machines in class. Laboratory practices. Projection of presentations with slides. Experiments in the classroom or in the laboratory. Editing a school newspaper.

3.2. Science learning in children

Stella Vosniadou (2003) in his work *How children learn* summarises what teaching research has found in the last 35 years. She gives these recommendations:

1. Active involvement. Learning requires the active and constructive involvement of the learner.

2. Social participation. Learning is primarily a social activity and participation in the social life of the school is central for learning to occur.

3. Meaningful activities. People learn best when they participate in activities that are perceived to be useful in real life and are culturally relevant.

4. Relating new information to prior knowledge. New knowledge is based on what is already understood and believed.

5. Being strategic. People learn by employing effective and flexible strategies that help them to understand, reason, memorise, and solve problems.

6. Engaging in self-regulation and being reflective. Learners must know how to plan and monitor their learning, how to set their own learning goals, and how to correct errors.

7. Restructuring prior knowledge. Sometimes prior knowledge can stand in the way of learning something new. Students must learn how to solve internal inconsistencies and restructure existing conceptions when necessary.

8. Aiming towards understanding rather than memorisation. Learning is better when material is organised around general principles and explanations, rather than when it is based on the memorisation of isolated facts and procedures.

9. Helping students learn to transfer. Learning becomes more meaningful when the lessons are applied to real-life situations.

10. Taking time to practice. Learning is a complex cognitive activity that cannot be rushed. It requires considerable time and periods of practice to start building expertise in an area.

11. Developmental and individual differences. Pupils learn best when their individual differences are taken into consideration.

12. Creating motivated learners. Learning is critically influenced by learner motivation. Teachers can help pupils become more motivated learners by their behaviour and the statements they make.

3.3. Intellectual procedures involved in scientific activity

As we already know, science is a collective human construction that is characterised both by knowledge (product) and by the methods used to obtain and validate it. The product depends on the followed path.

The so-called ‘scientific method’ is not what many people believe: a chain of steps that leads to infallible knowledge. The reality is more complex and the process is less defined and determined. Even so, science tries to validate its productions very carefully and that is why it makes use of the entire community. On many occasions, the judgment on the validity of a proposal is made by reviewing the path (the process) that has been followed: if the process is not rigorous, precise, and free of researcher prejudice then the product is not accepted. Thus, the path (the method and skills involved) is of great educational importance.

The following table shows the intellectual procedures involved in scientific activity, according to Phardan (2000):

Skills	Definition	Example
Observing	Using your senses to learn about objects around you. You observe by seeing, smelling, and so on.	Seeing wood catch fire, hearing the cracking of burning of fire; and smelling the smoke.

Classifying	Putting objects into groups. All objects in a group are alike in some way.	Grouping plant leaves according to shape, size, colour, texture, or type of edges; placing organisms in a similar (or common) relationship between people or groups.
Inferring	Using what you observe to explain what has happened	Concluding that it has rained this morning because the pavement is wet
Communication	Telling what you know by speaking, writing, drawing picture, or graphs	Giving an oral or written report, drawing a diagram; or developing a flow chart about one food chain within a larger food web.
Measuring	Finding out the size, volume, mass, weight, or temperature of an object.	Using a meter stick to find out how tall a tree is; finding the mass of rock with a spring balance; using a watch to find out how long it takes for an ice cube to melt; using a thermometer to establish how hot water is.
Using numbers	Includes: ordering, counting, adding, subtracting, multiplying, and dividing numbers	Putting objects in order according to their masses, beginning with least amount of mass; calculating the mechanical advantage of a machine. Plotting a graph of temperature against time.
Predicting	Proposing possible outcomes of an event or experiment. Predictions are based on earlier observations and inferences.	Stating that blue litmus paper will turn red when dipped in lemon juice; stating how long it will take for a cup of water to freeze if it is placed in a freezer.
Interpreting data	Explaining the meaning of information that has been collected.	Reading a graph about use of fossil fuels and concluding that more industries use coal than natural gas; studying daily weather tables and concluding that cities along coast get more rainfall than those in deserts. Reading a table (or pie charts) about nutritional values of different foods.
Controlling variables	Making sure that all factors in an experiment stay the same	Changing the amount of salt in a recipe the second time you prepare

	except the one which is manipulated	it but keeping all other ingredients, temperature, cooking time the same.
Hypothesizing	Making an educated guess about how or why something happens. A hypothesis can be tested to see if it is supported or not.	Proposing that 'bean plants grow taller in infrared rays than in white light', which is then tested in an experiment.
Experimenting	Testing hypothesis and predictions.	Designing and carrying out an experiment to determine whether ocean water freezes at a lower temperature than tap water.
Defining operationally	Forming a definition that is based on what you do or what you observe. It tells how something acts, not what it is.	Defining acid as any substance that will turn blue litmus paper red; defining a paper airplane as an object made of paper that will fly for a certain amount of time.

Notes:

1) 'Observing' is unobservable, as is 'understanding'. On the contrary, 'classifying' or 'answering correctly to inferential questions' is observable. Sometimes intellectual skills must be assessed through indirect tasks.

2) In science, a great deal of attention is paid to 'non-falsifiable hypotheses' or those hypotheses for which is impossible to test their falsehood (or truth). Hypotheses must be falsifiable or refutable, as the philosopher Popper taught us. Examples of unacceptable non-falsifiable hypotheses are: 'The devil is the culprit of natural disasters' (the devil has no place in science because it is not a physically detectable entity, at least for the moment ;-); 'Our universe belongs to a bigger one, and this one belongs to a bigger one...' (as you cannot leave your universe, you cannot verify this idea). The following circular pseudo-hypotheses must also be avoided: 'this child does not learn because he is not very intelligent', but the greater or lesser intelligence of that child is being evaluated through the learning observed in the classroom, so that there is no independent confirmation of his intelligence.

3.4. Science process skills

Process skills are those mental and physical skills involved in acquiring information, selecting it, then processing and using it. These procedural skills help develop ideas about the world around us through the collection and use of appropriate evidence.

The process skills, related to inquiry learning, that must be worked on during primary education are the following:

Posing questions

Children are curious and ask questions about the world around them. The *teacher* should help pupils identify the researchable nature of a question and formulate questions that may lead to the design and execution of a school inquiry or investigation.

Observation

Pupils should be able to use their senses to obtain information and separate the relevant from the irrelevant in their investigations of the world around them. In addition, they must be able to relate several observations and find patterns or sequences. Pupils also need to be aware of what is observed, selected, and interpreted based on previous ideas and expectations, so there will always be information to use.

The *teacher*, therefore, should provide enough opportunities for pupils to make numerous observations, paying attention to all the details and not just what is obvious, and without forcing them to focus only on what is relevant because it can lead for pupils to try to see 'what they have to do', instead of what seems important to them.

Hypothesis formulation

This processing skill is to suggest tentative explanations to try to explain observations or make predictions in relation to a principle or concept. Sometimes this principle or concept has already been established from previous experience and it is only a matter of applying it to a new situation. Other times, it may seem more like the beginning of a new principle or the verification of a feeling. This enables pupils to understand the provisional nature of scientific knowledge, always subject to conflicting proof or to change in the event of new evidence.

The *teacher* must select or prepare phenomena, organise groups to discuss possible explanations, provide access to new ideas that pupils can add to their own.

Prediction

This can be based on a hypothesis, or a pattern detected in the observations. Neither hypotheses nor predictions are guesses since they are rationally based on an idea or observations. It is not easy to encourage pupils to make authentic predictions, rather than guessing or simply stating what is already known.

The *teacher* should provide occasions when pupils can investigate their ideas by making and checking predictions; talk with them about how to make a prediction and test it; invite them to make predictions about something that is not known beforehand to check their ideas.

Research

This refers to the planning and development of the investigation itself after having posed the question to be investigated. Its steps are:

1. Define the problem in operational terms.

2. Identify what will be modified in the investigation (independent variable).

3. Identify what should remain the same so that the effect of the independent variable (variables to be controlled) can be observed or measured.

4. Identify what you want to measure or compare when the independent variable (dependent variable) is modified.

5. Consider how to use measurements, comparisons, or observations to solve the original problem.

The role of the *teacher* is to provide problems, but not instructions to solve them, giving pupils the opportunity to plan the resolution; provide the planning structure appropriate to the children's experience; sometimes discuss plans before putting them into practice and considering different ideas. Always comment after the activities, to consider retrospectively how the method could have been improved.

Reaching conclusions

This involves gathering various pieces of information or observations and deducing something from them. Pupils too easily jump to conclusions based on limited evidence. This is the most important part of the practical activity because it involves comparing the initial ideas with the new tests and deciding if the results fit or if you need to try other ideas. It is at the core of active learning, where mental activity and practice come together, and must be given sufficient time in planning.

The *teacher* should help pupils distinguish between the available evidence and the inferences that go beyond it.

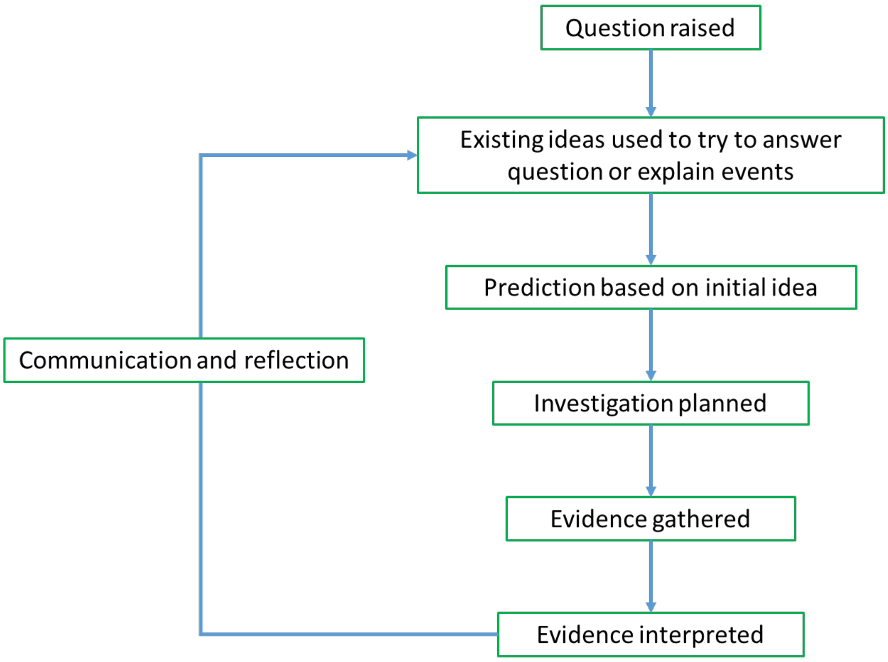
Communication

This is an extension of thought to the outside, so it is valuable for the process of recomposing thought, relating one idea to another, and thus filling in some gaps in the student’s framework of ideas. It often provides access to alternative information or ideas that aid understanding. Other times it helps to overcome a comprehension difficulty without apparently having produced any new contribution in the communication. It includes both verbal communication (spoken and written language) and non-verbal communication (symbols, drawings, diagrams, tables, and graphs).

The *teacher* should organise the class so that the pupils can work and speak in groups; introduce a set of techniques to record information and communicate results; analyse the adequacy of the ways of organising and presenting the information in relation to the objectives.

An important support for educational intervention to improve the capacity of observation in the different phases of the process is the use of questions that promote the identification of details, the description of what is observed and the comparison of elements, which can lead to the elaboration of explanations from what has been observed. These questions can be closed, focused on a specific characteristic, or open when they can elicit a set of responses.

A generic inquiry-based learning process outline, based on the procedural skills discussed, and which we will explain in detail in Section 3.6.1, could be the following (Harlen, 2003):



Inquiry framework (source: Harlen et al. [2003])

3.5. Cognitive development in primary school children

The degree of cognitive development of pupils is very different between the beginning and the end of primary education (in fact, this is the educational stage in which a student develops the most cognitively). Therefore, although the same topics can be studied at various stages they cannot be addressed in the same way. Below are the characteristics and appropriate activities for pupils in each of the cycles of primary education, according to Harlen (2007) and Jara, Cuetos and Serna (2015).

3.5.1. 6- and 7-year-old pupils

Pupils of these ages are capable of more complex operations than in early childhood education and they also have a greater capacity for abstraction. In addition, they can integrate a greater number of elements of the world around them into their thinking and systematise them into ideas and concepts, although their thinking only revolves around their personal experience with reality. The **main characteristics of how pupils think** at these ages are:

- As their experience is quite limited, their ideas are supported by a few specific cases as far as new experiences are concerned.

They can only focus on a single aspect of objects and situations, so they are not able to establish relationships between the various characteristics or elements (e.g.: Sun, water and air are needed separately for plants).

- In a sequence of events, they are not able to relate the events to each other, understanding the first and last step, but not the intermediate stages. Therefore, they cannot see patterns in events.
- They are still developing the concept of cause-effect, so in the proposed experiments, they must work with a single variable, since they are unable to see the effects of several variables separately.
- They see the facts from only one point of view, their own, except if they are physically transferred to the other position.
- They need to perform an action to see its consequences or results, so they must explore and manipulate objects and phenomena in the first person to relate the action to their thinking.

Therefore, the **main characteristics of the activities** for these students are:

- The starting point should be particular and everyday cases that they may find with their family and their specific environment. You can then gradually introduce more complex experiences (e.g.: shopping, pets, the park, or holidays).
- Discussion, questioning, explanation of phenomena, and use of the senses should be encouraged. You should try to expand their ability to understand and express themselves, as well as their vocabulary.
- Attractive activities should be proposed where pupils experience the different phenomena as if it were a game (such as making ice cubes and watching the water melt).
- Manual and creative work should be encouraged: the use of paints and modelling clay to experiment with shapes and test textures.
- Construction games, puzzles, and models are suitable for recognising shapes, volumes, learning geometry, and promoting lateralisation and spatial organisation.
- It is essential that pupils have contact with the environment and nature, as well as with the fauna and flora of their environment (such as observing animals and plants, the changes of the seasons of the year, and making small herbaria with leaves or fruits).

3.5.2. 8- and 9-year-old pupils

Pupils of these ages can already understand more abstract and complex concepts, so they begin to be able to replace some actions with thinking. They also begin to develop cognitive reversibility, they begin to be able to think of a simple process in reverse, and the notion of conservation of surfaces (i.e.: they begin to understand that, if a ball of clay is divided into several pieces, the sum of the pieces is equal to the original ball), which enables determining the qualities of the objects regardless of the changes they undergo. This is a great advance as they can understand a simple process and the sequence of its stages. Pupils of these ages have greater social integration with their peers and show interest in a great diversity of topics, which is an advantage for carrying out very diverse activities in groups or pairs. The **main characteristics of pupils' thinking** at these ages are:

- They can think through the different stages of a simple process and modify the order.
- They can understand more complex cause-effect relationships and relate them to the mechanism that generates them. Therefore, the number of variables used to observe their effects can be increased, although they are not yet able to see the interrelationship that exists between them.
- There is progress in the ability to see things from the point of view of others, especially if they experienced this perspective.

Therefore, the **main characteristics of the activities** for these students are:

- Fewer familiar situations should be presented, and more abstract aspects should be expanded (e.g.: meteorological phenomena and spatial location).
- The impression and visual capture of pupils is essential to understand and build new mental models.
- Group and collaborative activities should be worked on, giving the opportunity to organise, classify, and share materials.
- Activities that enable answers to the questions posed should be encouraged, as well as simple scientific skills such as observation, comparison, and classification. More complex skills such as the search for guidelines and details, the relationship between observations or description of causes-effects (such as the observation of seed germination, plant growth and the life of silkworms) should also be encouraged.
- Activities should be proposed to help them explain how objects work or how various phenomena occur, with the use and management of models (physical or interactive models) of the human body, the senses, the parts of living beings, etc.
- Measurement and estimation with the use of magnitudes, measuring instruments, and operations with instruments should be worked on. There are quantities that are easier for them (length and area) and others that are more difficult to understand (mass, time, and temperature). It is also necessary to work

on the use of materials and their uses (experimenting with the concepts of hard, flexible, transparent, strong, and so on) and the relationships between the properties of materials, their uses, and their forms.

3.5.3. 10- and 11-year-old pupils

Pupils of these ages begin to perform operations and handle concepts of greater difficulty and are able to face a more rigorous way of thinking and more complex phenomena. On an emotional and affective level, students begin adolescence, where the peer group plays a very important role and with whom they begin to define their own identity. The **main characteristics of pupils' thinking** at these ages are:

- More abstraction and objectivity enables them to work with several variables and separate their effects and interrelations, even if only in simple cases.
- They can execute all the steps of experimentation, not only the observation and obtaining of data, but also the preparation of hypotheses and the drawing of conclusions.
- They begin to understand and apply the scientific method to verify ideas with empirical tests, being able to design simple research plans and make logical deductions.
- It is not necessary for them to physically see a phenomenon to understand or think about it, since they are able to generalise their learning and relate it to situations external to their reality.
- They have increased their attention span and the time they can focus on performing the same activity.

Therefore, the **main characteristics of the activities** for these students are:

- The application of the scientific method should be encouraged, with observations, measurements, hypotheses, and synthesis of the conclusions obtained.
- Situations that allow the use of simple techniques and procedures must be considered: dissolutions, precipitation, changes of state, decompositions, etc., as well as the use of instruments that expand the senses and measuring instruments.
- Activities should be promoted for students to explain phenomena and objects, pose questions, and solve practical problems of various kinds.
- It is a very appropriate age for the introduction and awareness of environmental problems: biodiversity loss; air and water pollution; waste management; responsible consumption; and environmental education.
- Scientific workshops and construction of small models can be carried out: electrical circuits; decomposition of light with prisms; terrariums or aquariums; etc. that will make students want to ask questions.
- Communication and interpretation of results should be encouraged, as well as searching for information from different sources to support their data and expand their knowledge.

Here is an example of how the understanding of a particular phenomenon progresses with age:

For 6-7 year old children

For 8-9 year old children

For 10-11 year old children

The water cycle for different cognitive stages

3.6. Practical work in primary school science

Homer Lane (1875-1925), Dewey (1870-1952) and Montessori (1870-1952) gathered previous ideas from Rousseau (1712-1778), Pestalozzi (1746-1827), and Froebel (1782-1852) and recognised the importance of pupils playing an active role in their own learning. Education should consider the importance of curiosity, imagination, and the need to interact and explore the world of children.

Pardhan (2000) tells us: from a teaching point of view, learning science is 'doing science'. Doing science is exciting for pupils when they are actively engaged in an adventure in which they can be participants and even protagonists. Doing science involves using the typical scientific process skills that help pupils to increase their knowledge from experience. Well-designed manipulative experiences facilitate the learning of simple ideas, which are then combined and form more complex ideas.

Practical work in science has several educational advantages (already discussed in chapter 2 and repeated here).

1. From the cognitive point of view, the manipulation of **reality** (although in simplified conditions and limited contexts) facilitates its understanding when compared to the study through symbolic mediators (such as text, drawings, graphics, and photos). If you are going to study natural reality, why not go directly to it? Why mediate with texts, diagrams or even images? It seems more appropriate that symbolisation processes (abstract) appear

after reality itself has been perceived (objects and events); after it can be described in terms of everyday life (more specific and less abstract) and a level of maturational development that enables abstraction (states, phenomena, and laws) has been acquired.

2. The **image** that is transmitted about science is very distorted if you only work using textbooks or films where the student tends to be passive. In science 'knowing how to do' is as important as 'knowing how to say' and it helps gain an understanding. Manipulating reality will obtain answers to previously formulated 'human' questions (hypotheses, predictions) or even to obtain new questions. This is the most exciting creative activity of a scientist. Although in simplified situations, we should not deprive pupils of the possibility of feeling like scientists.

3. Another argument in favour of experimental activities is that, if they are carried out in small groups, they enable the monitoring of **educational objectives** (attitudes, behaviour, collaboration, respect, division of labour, order, responsibility, etc.) and other objectives. Purely conceptual activities (typical of reading and 'turning the pages' of a book) are individual and can hardly develop socialisation with all of the involved civic values.

4. Finally, manipulative activities are much more **fun** for pupils: although fun is not the object of the activities, it is true that it stimulates, leaves good memories, and encourages positive attitudes towards science that can last a lifetime (whether the person dedicates himself to science or not).

The manipulation of materials and devices involves the use of other parallel cognitive resources that involve specific parts of the brain that process corporeity and the environment (effects of embodiment analysed by Barsalou, 2012). In comprehension and problem-solving tasks, advantages have been found in the manipulation of real material and devices compared to displaying (without manipulating) images (Ferguson & Hegarty, 1995). The benefits of witnessing things as they are, and not having to imagine them from static images and/or text can be added to the manipulation itself. The theory of cognitive load of Chandler and Sweller (1991) affirms that understanding is facilitated (cognitive load is reduced) when students can see in action the reality that the teachers want to show (especially, phenomena that occur over a period) compared to a situation in which the process or procedure has to be reconstructed from text and/or static images (photos or diagrams).

3.6.1. Models in science education

Because pupils still do not have well-developed abstract thinking, it is often difficult for them to understand scientific topics through representations, although it is useful to introduce topics little by little (also to help them develop their abstract thinking). The main reason is that, if it is not through representations, we cannot bring certain phenomena to the classroom because they are far from the human scale, either very small, microscopic (cells and atoms) or very large (stars and the atmosphere).

Models are invented as representations of a real phenomenon that explains the observations we make (Ornek, 2008). We can make these representations using drawings, models, objects, simulations, formulas, or even our own body. Each tool has its advantages and disadvantages and is useful depending on the phenomenon studied.

It is important to understand that the model is necessarily a simplification of the real phenomenon, because otherwise it is no longer useful and is not too predictive. Therefore, within modelling, the most complicated thing is to decide which real variables of the phenomenon to include and which to leave out. We can leave variables out because they cannot be represented due to limitations of the tool we are using or because it is not relevant to the object of study. For example, if we are studying the lunar phases, the movement of the Earth around the Sun can be ignored because it does not influence the phenomenon.

3.6.2. Inquiry learning

People learn best when they are actively involved in learning tasks (when they are concerned and held accountable). But this advises teachers to facilitate, motivate, encourage, and provide the means so that students can learn actively. Active learning with educational goals takes time: students must 'own' the task and learn to collaborate in a fruitful way. Therefore, do not believe that every practical activity is equally useful for science education.

An especially helpful way of approaching science education, while respecting its potential benefits is 'inquiry learning'. The US National Research Council defines inquiry as 'a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories...and learn science in a way that reflects how science actually works' (NRC, 1996: p.214).

Below, you will find the principles, pedagogical considerations, and implications of inquiry-based learning according to Harlen (2012):

Principles of inquiry-based science teaching

- Direct experience is at the centre of science learning.
- Pupils must understand the problem they are investigating.
- To learn by inquiry, pupils must be taught a series of skills.
- Learning science is not only doing things, it is also reasoning, talking, and writing.
- The use of other sources complements direct experience.
- Science is a cooperative effort. Inquiry is a collaborative task.

Teaching considerations about inquiry learning

1. Organising the classroom: groups need space to work together and access materials, as well as places to store their work.

2. Encouraging collaborative work: there should be a classroom climate in which pupils feel comfortable and can participate in all aspects of scientific work.

3. Asking productive questions: questions play a very important role. The productive ones encourage students to think about their own questions and how they can find the answers.

4. Using the prior experiences and ideas of pupils: teachers should consider these ideas and adapt activities so that more coherent explanations emerge.

5. Helping students to develop and use inquiry skills: they should have the opportunity to use them and discuss their use. Experience and knowledge increases when pupils engage in research and data collection tasks, but without discussion, reflection, and review, this knowledge can be patchy and fragile.

6. Holding discussions: throughout the entire process, in pairs, in small groups and with the whole class.

7. Guiding student recording: records include texts, drawings, diagrams, graphs, posters, etc. Students can keep notebooks and prepare written reports to present, and can use these to assess the progress of pupils.

8. Using assessment to aid learning (formative assessment)

Implications of inquiry-based science teaching

… do more of this	**… do less of this**
Having pupils seated so that they can interact with each other in groups.	Having pupils seated in rows working individually.
Encouraging pupils to respect each other's views and feelings.	Allowing pupils to force their own ideas on others, and not listen to others.
Asking open questions and ones that invite pupils to give their ideas.	Asking questions that call for nothing more than a one-word or short, factual response.
Finding out and taking account of the prior experiences and ideas of pupils.	Ignoring ideas from pupils in favour of ensuring that they have the 'right' answer.
Helping pupils develop and use inquiry skills of planning investigations, collecting evidence, analysing and interpreting evidence and reaching valid conclusions.	Giving pupils step-by-step instructions for any practical activity or reading about investigations that they could do for themselves.
Arranging for group and whole class discussion of ideas and outcomes of investigations.	Allowing pupils to respond and report individually only to the teacher.
Giving time for reflection and making reports in various ways appropriate to the type of investigation.	Giving pupils a set format in which to record what they did, found, and concluded.

Providing feedback on oral and written reports that enables pupils to know how to improve their work.	Giving grades or marks and allowing pupils to judge themselves against each other in terms of marks or scores.
Providing pupils with a clear picture of the reason for tasks so that they can begin to take responsibility for their work.	Presenting activities without a rationale so that pupils encounter them as a set of unconnected exercises to be completed.
Using assessment formatively as an on-going part of teaching and ensure student progress in developing knowledge, understanding, and skills.	Using assessment only to test what has been achieved at various times.

The starting point in any inquiry is a problematic question, that can be formulated by students or teachers. This question is what causes primary pupils to make observations, analyse information, make predictions, and formulate hypotheses in a way that they can overcome their alternative children's ideas and a meaningful, interrelated, and functional knowledge is acquired. Here are some examples of suitable questions to investigate in different scientific topics (Cañal, García-Carmona and Cruz-Guzmán, 2016).

Electrical phenomena
How can we electrically charge an inflated balloon? And discharge it? Which materials in our surroundings are electrical conductors and isolators? Why are electrical wires covered in plastic? What is the role of a light bulb in an electric circuit? How is the electricity that we use at home produced? In which types of energy is the electrical energy at home transformed? How is light produced in the dynamo of a bicycle? Which of the machines that you have at home consumes the most electrical energy to function? And the least? How does a lightning rod work? Why shouldn't we touch electrical devices when we are wet or barefoot? How do you think our lives would be if we suddenly had no electric power for a while (a day, a week, a month, a year…or forever)? Which measures would you adopt to make a responsible consumption of energy at home?
Magnetic phenomena
What material should a refrigerator door be made of so that we cannot stick magnets on it? If you had a metal and a magnet of the same colour, size, and shape, how would you find out which one is the magnet? Why is the earth said to be a magnet and what could be the cause? Why can we orient ourselves with a compass?

How can we build our own compass? What uses do you see for magnets in daily life? How can you build a homemade magnet?
Sound-related phenomena
Why does a flute sound when we blow it? Could we play a guitar on the moon? Why? Why are some sounds more unpleasant than others even though they have the same volume? Why can people talk? How would a guitar sound with loose strings? Why? Where does sound travel faster, by water or by air? Why? Why during a storm do we see first the lightning and then hear the thunder? Why do you think living beings have two ears instead of just one? How can we build a simple telephone with homemade material? What volume of sound do we usually produce daily in class? What health problems can noise cause?
Light-related phenomena
What difference do you think exists between the light emitted by a light bulb and sunlight? What factors determine the size of an object’s shadow and why? What is a solar eclipse? How can we verify that light carries energy? Why can we see ourselves in a mirror? Where is the image of our face when we look at ourselves in a mirror? How would you write your name on the front of a car so that other drivers could read it well through their rear-view mirrors? Why when we submerge part of a pencil in a glass of water do we see it crooked? In what transparent liquid could it be submerged so that it does not look crooked? How would you classify the materials in your class according to their behaviour in light? What gadget can we build to see objects on the horizon if we are in a ditch? Do you think white light is really white? Why? How is the rainbow produced and how can we do it? Do objects always have the same colour? How does a magnifying glass work? How do binoculars work? Why do you think that people and many other animals have two eyes? How can we build a homemade photo machine?
Machines
How many machines do you know? What are the machines you know and what problems would there be if they didn't exist? What do a shovel and a fishing rod have in common and how are they different?

How many different types of machines are there in your house?
What criteria do you use to distinguish the different types of machines that you have at home?
Of the machines you know, which ones would you classify as simple machines and as complex ones? Why?
What types of machines are the following and why: tweezers, microwave, car, can opener, corkscrew, bicycle, and a fan?
What does any machine need to start working?
How does a bicycle work?
Why do many motors have a fan?
Where does the energy that the machines need to work come from?
What energy transformations occur in the machines in your house?
Why do some machines get old?
What would your life be like if the machines you have in your house did not exist?

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4. ADDITIONAL INFORMATION

4.1. Information and teaching suggestions for the different topics

4.1.1. Earth, Sun, and Moon

There is a lot of teaching work to relate ‘what is seen from Earth’ with ‘what would be seen from space’. The activities should include the manipulation of flashlights and movements of the pupils with them in the classroom (embodiment of movements and positions). It should not be forgotten that three-dimensional models cannot be well represented on the blackboard or in book illustrations (although better in movies). Understanding the origin of the seasons can be facilitated by observing that the angle at which the sun’s rays strike the ground changes throughout the day, and changes throughout the year (taking measurements at the same solar time). To do so, it is convenient to work with projected shadows (a phenomenon well known to pupils from an early age).

4.1.2. Movement and forces

In primary education it is sufficient to ensure that pupils associate the origin of forces with material entities (objects) and not ‘invent’ forces associated with the direction of movement. Therefore, recognising and drawing the forces that act on a given object, not associating force and speed, describing the state of motion of a body based on its initial impulse and its forces, is sufficient. In advanced concrete operations ages, the joint effect of two forces can be taught: parallel, anti-parallel, at right angles. For this, springs and rubber bands can be used to create forces. Marbles, balls, skittles, inclined planes, etc. are sufficient for the activities on this topic. Controlled observation of traffic can even be carried out (measurements of spaces and times, for example).

4.1.3. Matter

From a teaching point of view, the objective is to associate matter with its properties and to extend the perception of these properties beyond sight or touch. From a scientific point of view, substances differ and are characterised by properties. Therefore, we can use what they already know (that solids and liquids are matter) to introduce the description based on their properties (for example, what makes solids and liquids different? What does a group of hard, or elastic, or rigid, or shiny solids have in common? Working on the classification of materials helps their conceptualisation at more elementary levels. It is enough if at the end of primary, pupils understand (among other things) that every entity that has mass and volume is matter, and if it has neither mass nor volume it is not matter. It is interesting to try to show that properties such as the melting or boiling temperature of a substance are specific to each substance and therefore define them.

Phase changes can be worked on experimentally, but the presence of a heat source represents a risk of an accident that must be avoided. Handling MUST BE CARRIED OUT BY THE TEACHER to avoid accidents.

4.1.4. Buoyancy

Floating is a fun topic to work on for all ages. Just because a young child cannot understand Archimedes' principle does not mean that the subject should not be discussed: we should not pretend to climb a long staircase in one jump. There are intermediate learning objectives that are interesting and important. It is a subject where there should be no danger to pupils, and they can manipulate objects in small investigations. Let's try to sequence and order the teaching work. There are many variables involved and you must work on them with order and simplicity. You can start with the flotation of solids in water leaving liquids other than water and the flotation of liquids in liquids for later.

Gather a (large) set of objects with differing shapes, volumes, weights, and materials and collect sufficiently large (not deep) containers of water. We can select pairs of balls of the same volume but with different weights, pairs of objects of the same weight but of different shapes or materials. In this way, the members of each pair can be compared. The objective is to rule out the single influence of weight and volume. Pupils are led to see that there are very large objects that float and other small ones that do not (for example, a screw or a key). There are heavy objects that float and light ones that do not (like a screw). At the same time, certain materials always float (whatever the weight or whatever the volume) and other materials float or not depending on their shape. It not necessary to immediately consider the idea of 'density' as mass divided by volume.

4.1.5. Heat and temperature

Heat is a form of energy. It is the energy transmitted from a body at a higher temperature (hotter) or another at a lower temperature (colder), due to their difference in temperatures. Pupils cannot be expected to understand heat or define it in words until they are older.

Instead, we can work with this concept in different experiences so that its use creates the concept by abstraction from the diverse reality.

Thermometer measurement is easy to introduce because medical thermometers are used in almost every home. You can start by proving that the sensations of hot and cold are deceptive and that it is necessary to have a measuring instrument that does not deceive us. The home knowledge of heat as linked to flames or the hob with which food is cooked can be taken as a basis to use the concept of heat (correctly but without asking pupils to define it) and differentiate it from temperature: we can heat the same volume of water with a small flame and with the large flame and measure how its temperature increases. Children will see that the temperature of water heated with a large flame increases more quickly than the water heated with a small flame, but that the latter also increases. They can associate heat with what the flames supply and which increases the temperature of water. Large flames (or plates) heat more quickly because they transmit heat faster than small ones. However, the temperature also increases with small flames, although more slowly.

In the experiments with first and second-cycle pupils, the handling MUST BE CARRIED OUT BY THE TEACHER to avoid accidents. Third-cycle pupils can handle working materials work but using alcohol lighters and always within a safe temperature range (do not let them boil water!).

4.1.6. Electricity

Circuits are poorly understood, even by adults. We should be very careful with the water pipe analogy because cables are not hollow pipes. On the contrary, it is the electrons from the same cable and other conductive materials that move to form an electrical current.

Batteries are NOT stores of charge: they do not supply electrons but rather push them as they reach their interior. When they are depleted, what they have lost is the ability to push charges and make them move around the entire circuit (they are not depleted because they have exhausted their charge). It is correct to think that batteries are depleted of energy (not electrons!). In fact, generators are constant voltage providers and the amount of current that results depends on the entire circuit. When you change an element of the circuit, the current that flows, even with the same battery, changes. All the elements of a circuit, collectively and in a coordinated and simultaneous way, are responsible for the current that circulates and, therefore, for what happens in the circuit.

Each atom of a conductive material is balanced with positive and negative charges. It does not allow electrons to be added or easily lost. When a potential difference occurs (a battery is connected), enough energy is supplied to rip electrons from the atoms (only the outermost ones) and cause them to circulate. However, they must all circulate at the same time: the electron that jumps from atom B to the neighbouring atom C, leaves a hole so that an electron from the previous atom A can pass to the atom B: A→B→C... and so on until the last electron jumps back to the first one closing the circuit. If there is no hole, an electron will not jump from one atom to another and the whole circulation will be paralysed at once.

As the movement of each electron depends on the movement of all the rest, the amount of current, or intensity in a circuit is the same before a light bulb and after it: electrons are not consumed but is energy is transformed into heat and light in this case.

There are experiments for static electricity. These are highly recommended for their attractiveness, simplicity, and ability to motivate and stimulate curiosity. If they are well studied, they give rise to the understanding that there are charges in matter, that some can be transferred from one body to another and so create attractive or repulsive forces that enable ‘playing’.

4.1.7. Light

It is not convenient to go into sophisticated definitions or declarative teachings, but to make pupils play and be fascinated with simple luminous phenomena. Today it is possible to obtain fine quality pointers with which to generate reflections and refractions in buckets of water, or of water with a little added milk, or in mirrors and lenses. There is a set of very striking and motivating simple experiments for which you need materials that are affordable and durable.

There are four key concepts that we must address:

1) Light is a signal that travels through space and most optical phenomena are associated with that travel.

2) Light can be understood as composed of an immense number of rays that can travel in all directions and in a straight line until they encounter matter, or until they change medium. It is those rays that travel through space, pass through a lenses, or are reflected in mirrors. Each ray travels independently of the rest but following the same laws.

3) To see an object, the light must fall on that object which, in turn, reflects a part of that light towards our eyes. It does not matter that the eye is in the dark, or that there is a lot of ambient light: what matters is that a part of the light enters the eye from an object.

4) Light rays from a part of an object always reach us in a divergent way (they open up). By evolutionary adaptation, our brain always places the objects that we see at the point in space where the rays entering our eyes would converge, if we extend them back towards their place of origin.

4.1.8. Magnets

Working with magnets is fun but delving into magnetism is complex and unnecessary. Pupils can build simple toys and games using magnets. The properties of these are gradually internalised without the need to use complex terms or concepts (magnetic field, lines of force, etc.).

It is interesting to learn the existence of action at a distance, dependence of force with distance, attractive and repulsive forces, materials that allow the action of the magnet to ‘pass’ through, and materials that ‘block’ the action of the magnet, materials that become temporary magnets themselves when near to a magnet, and materials that are unaffected by magnets. Pupils should learn the fact that appearance is unimportant (large or small objects, with or without a metallic appearance). You can build a magnet with a coil of wire connected to an electrical current (electromagnets). If we move a magnet near a coil, we create an electric current in it. They should also learn about magnet applications.

4.1.9. Sound

Sound is an auditory sensation in our brain, but it is caused by a wave that propagates through a material medium to our ear. The fact of conceiving that there is a mechanical wave making a material vibrate, and that there is no sound without that vibration, can be difficult. Therefore, conducting simple experiences where sound is shown to imply that something is vibrating is a good start. The human experience is that we always hear in the air; some pupils will know that underwater sounds are distorted or inaudible. Therefore, experiments must be carried out to show that water and solids can also vibrate and, therefore, conduct sound to our ears.

Beyond conceptualisation, the theme of sound invites you to have fun making music, noises, and creating instruments, etc. With the help of various instruments, the characteristics of sound can be altered in terms of tone and intensity but try to make it fun and part of ‘making music’.

4.2. The possibilities of visiting science museums and exhibitions

We should combine both indoor and outdoor education when possible. Science topics can also be worked from nature itself and from museums and exhibitions.

Over the last two centuries, but particularly since the 1960s, museums have looked for different ways to communicate with visitors and they are no longer just places where objects of artistic, historical, or scientific-technical value are stored and exhibited. Modern museums through museum teaching and education have developed specialised ways of working with different age groups, and have strengthened the experience of museum exhibits and exhibitions with informal learning. Museums are now social spaces for learning and knowledge.

There are a variety of methods that can be used depending on the type of visitor, user experience, target group, investment of time, and even budgetary resources. These include the usual guided tours, but also dialogues with visitors, scavenger or treasure hunts (with and without questions), learning by doing, creative processing, object analysis, associative activities, etc. Most of the big museums have programmes for children and there are children’s museums with exhibits and programmes to stimulate informal learning experiences. These museums feature interactive exhibits that are designed to be manipulated by children, because it is well known that activity can be as educational as instruction, especially in early childhood. However, a mediation process is necessary where teachers play a key role in the absence of a museum or exhibit educator.

We have many science-related alternatives here in Valencia to visit with primary pupils:

1) **Science Museum** (as part of the Ciutat de les arts i les ciències). There are interactive exhibitions and scientific activities to show new technologies and advances in science. It has over 26,000 square metres of exhibits on current scientific and technical matters. Full interactivity is one of its special features, the motto of which is 'It is forbidden not to touch, not to feel, not to think'. The approach used by the museum consists of a huge variety of seasonal exhibitions and scientific activities of all kinds to arouse the visitor's curiosity about new technologies and scientific advances, so as to generate a pleasant learning process in which the visitor always takes an active part and decides where they would like to go and what they would like to learn.

2) Natural Science Museum. Located in the Jardines del Real, the historical origin of this Museum dates to the end of the 19th century, with a gift that Rodrigo Botet made to the city of Valencia. This gift is the most important collection of South American Paleontology in Europe and gave rise to the continent's first paleontological museum. The suseum has several exhibition areas.

a) *Science and technology*. It shows how scientific knowledge is linked to technological advances – from the optical microscope to the electron microscope.

b) *A classroom from other times*. Tribute to science teachers who with very few resources were able to arouse curiosity for scientific knowledge.

c) *History of life and evolution*. A journey through the different epochs into which the age of the Earth is divided. It shows that the Earth and living beings are the result of a history of more than four billion years of evolutionary change, of which we have evidence thanks to fossils. The palaeontology of the Valencian region enables us to better understand the evolution of the landscapes and ecosystems in our territory over time until the appearance of man.

3) **Observatori del Canvi Climàtic.** The observatory supports the fight against climate change as well as showing the contribution of Valencia to sustainable development. It enables visitors to learn the causes and consequences of climate change and learn about the solutions, as well as training the participants for action. There are different modalities to carry out the activities: onsite and online (which is also very worthwhile for schools). It may be possible to arrange for a team from the museum to visit your school. It has

many resources such as interactive videos, exhibitions, and various educational resources. The focus can be on the following topics: water, energy, mobility, waste, food, or climate change.