

**THE LEARNING OF SCIENCES: A GRADUAL CHANGE IN THE WAY OF LEARNING.  
THE CASE OF VISION<sup>1</sup>**

**(El aprendizaje de las ciencias: un paulatino cambio de modo de conocer. El caso de la visión)**

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**Abstract**

Learning the scientific way of knowledge implies a change in the most implicit principles that guide comprehension, interpretation and explanation of scientific phenomena as well as a change in the type of associated reasoning. With the aim of favouring this type of learning, a teaching programme was developed in relation to vision and implemented with a group of secondary school students. The way of learning of these students was observed at different teaching stages. Findings suggest that during the learning process the way students learn seems to change gradually and that students construct “intermediate” models (right but incomplete) that become the basis for the construction of a systemic model proposed by school science.

**Keyword:** ways of reasoning; conceptual; epistemic and ontological changes; vision.

**Resumen**

Aprender el modo de conocer que la ciencia propone implica un cambio en los principios más implícitos que guían la comprensión, interpretación y explicación de los fenómenos y un cambio en el tipo de razonamiento asociado. Con el fin de propiciar dicho aprendizaje se diseñó una propuesta de enseñanza en relación a la visión que se implementó con un grupo de alumnos de educación secundaria. Se estudió el modo de conocer de estos estudiantes en distintas instancias de la instrucción. Los resultados obtenidos permiten concluir que durante el aprendizaje cambia paulatinamente el modo de conocer, construyéndose modelos “intermedios” (correctos pero incompletos) que sirven como plataforma para la construcción del sistémico modelo propuesto por la ciencia escolar.

**Palabras claves:** cambio conceptual; cambio epistemológico; cambio ontológico; visión.

**Introduction**

During the direct vision of an object, multiple processes occur not only in the physical world “exterior” to the observer but also in his/her interior, without him/her being conscious of these processes (Monserrat, 1998). The individuals are so familiar with the fact of “seeing objects” that great imagination efforts would be needed to realize that vision is the product of complex interactions that take place between light and objects (starting with absorption, selection and transmission phenomena) and between light and the visual system, which includes complex physical, chemical, biological, neurological and cognitive mechanisms.

From the intuitive knowledge, which is built upon phenomenological experience based on a realistic belief that implies the idea that the world is and behaves as the senses show it, it can be understood that in order to see one only needs to have eyes and to look at the object (Bravo y Rocha, 2008; Driver, Guesne y Tiberghien, 1989; Galili y Hazan, 2000; Viennot, 2002). However, from the science point of view, it is explained that one can feel or perceive when the light reflected by an object affects the eye of the observer, in which photosensitive cells are stimulated selectively, causing complex chemical reactions through which light energy turns into electric energy. Then, this energy is transported by the nervous system to the brains where, through a neurocognitive stimulation process, what one sees and the colour one perceives are interpreted (Monserrat, 1998; Falk, Brill y Stork; 1990; Feymann, Leighton y Sands, 1971).

Learning these scientific explanations and interpretations imply that the individual has to go beyond the learning of concepts, laws, models and theories. It also implies accepting the characteristics underlying this way of knowing as well as interpreting the world whose features and interpretations can be completely different from the ones of the intuitive knowledge. These differences are not only related to the explicative model but also to the ontological, epistemic and conceptual principles, and to the subjacent ways of reasoning. In figure 1 these differences are described and exemplified, according to what has been proposed by Chi, (2002), Vosniadou y Brewer (1994), Pozo y Gómez Crespo (1998) y Salinas de Sandoval y Sandoval (1996).

Learning scientific knowledge and, particularly the models proposed to explain the direct vision of an object would mean:

- To overcome naive/ingenuous realism, so as to relate intuitive ideas to the scientific ones, while identifying them as different ways of understanding the world, by means of which explanations at different levels of complexity and contextual validity can be developed. The passage from this way of understanding the world to another with a higher range of perspectives implies a complex change, since this process requires a gradual revision of the epistemic assumptions that underlie intuitive knowledge together with a reinterpretation of previous experiences (Vosniadou y Brewer, 1994).

- To overcome ontological restrictions imposed by intuitive ideas and to acquire the principles subjacent to the construction of scientific knowledge. The main problem of learning processes that need a change in the ontological categories (such as vision) might be due to difficulties in reinterpreting the phenomena in terms of interaction processes, as this seems to go against the intuitive tendency to understand them within the causal linear and unidirectional relations (Chi, 2002; Viennot, 2002).

- To overcome the conceptual restrictions imposed by the ideas that are built intuitively and that are gradually might lead to acquire the principles implied in the building of scientific knowledge, which implies the idea of overcoming the principle of “fact or data”, so as to accept interaction as a way of understanding these phenomena (Pozo y Gómez Crespo, 1998).

Results of a previous longitudinal research (Bravo, 2002; Bravo y Rocha, 2004; Braunmüller, Bravo y Rocha, 2003 1a; Braunmüller, Bravo y Rocha, 2003 1b; Bravo y Pesa, 2005) on primary and secondary school students (from 9 to 15 years old), suggest that, on one hand, the ways of explaining vision, described in table1, would build the two extremes of the continuum students may go through during the processes of the learning of sciences (when using formal teaching there is a deliberately need to placate ontological, epistemic and conceptual changes). On the other hand, these studies may point out that the learning of the models of science can be a gradual process, with slow progress and frequent withdrawals/retractions that would lead to gradual ontological, epistemic and conceptual changes (as it is proposed by Pozo y Gómez Crespo, 1998).

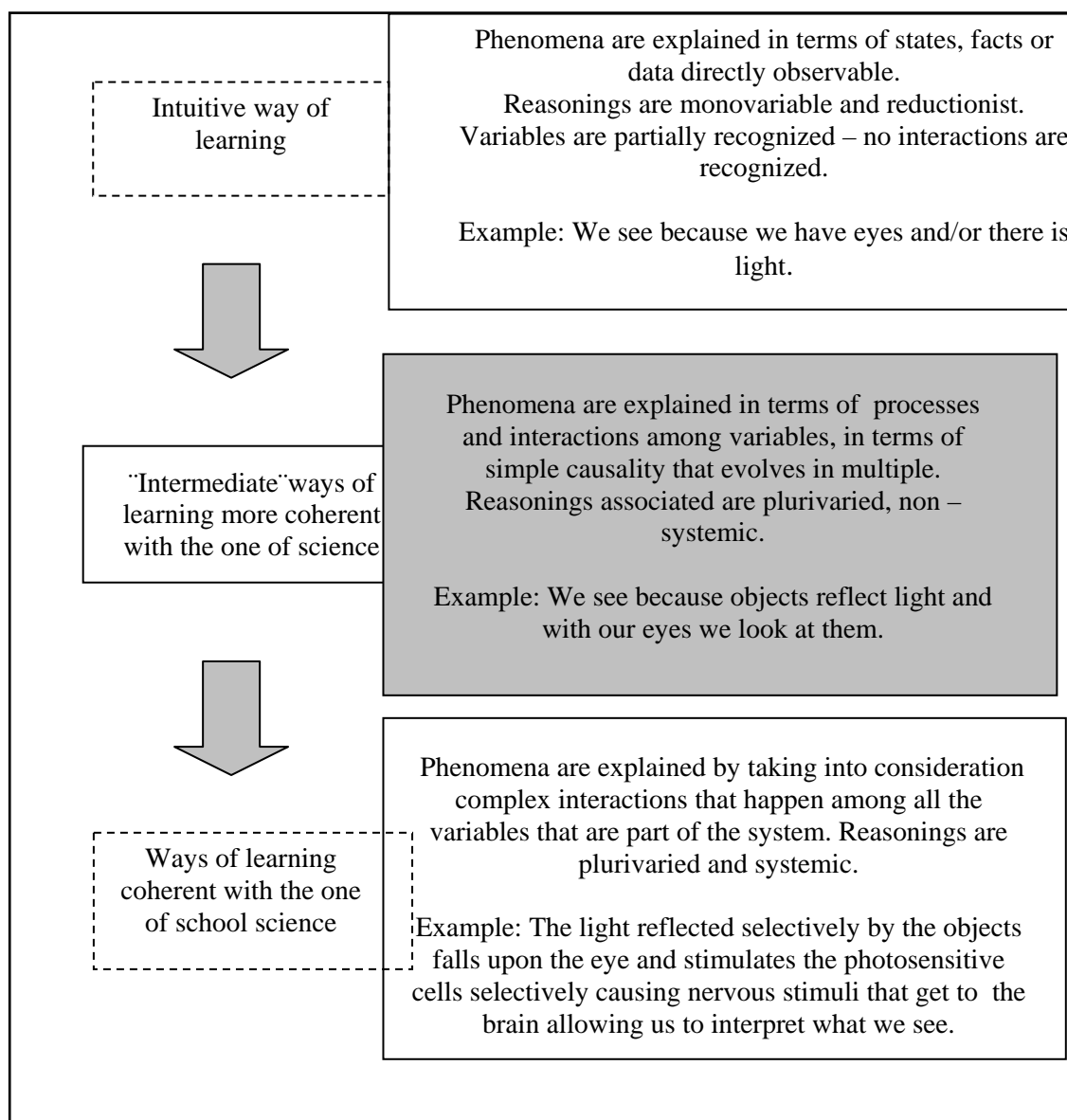


Figure 1. The learning of sciences as a change in the way of learning.

Concerning the first item, four ways of knowing have been identified that can let us believe that students may use them more frequently as they get involved in the process of learning to explain vision. In table 2, these ways of learning are presented in four categories characterized by the underlying explicative model (and by elements involved in the perceptive process and by functions and interactions identified) by the ontological, epistemic and conceptual principles and by associated ways of reasoning. The first two categories involve intuitive ways of knowing shared by students at the beginning of instruction. The third category involves a way of knowing that is the product of schooling, considered an “intermediate one” between intuitive knowledge and the one of school science, which, by the way, is coherent with the one science proposes though it is incomplete. Finally, the fourth category is underlied by the model of school science, which as it has been detected by Bravo y Pesa (2005), students of secondary school education may use them as a consequence of formal education.

INTUITIVE KNOWLEDGE		SCIENCE KNOWLEDGE
Explanatory knowledge	We see because we have eyes and look at the object	To see an object, the light reflected diffusely by the object has to influence and stimulate the visual system of the observer (stimulation that implies complex physical, chemical biological, and psychological processes)
Ontologic Principle	<i>State</i> Understanding the world in terms of states of matter that are disconnected among them.	<i>System</i> The phenomena are understood in terms of complex relations that are part of a system.
Epistemologic Principle	<i>Naïve/ingenuous realism</i> Reality is as we see it, so that what we can't perceive doesn't exist.	<i>Constructivism</i> It is conceived that science is composed of alternative models that allow for the interpretation of reality although these models are not reality itself.
Conceptual Principle	<i>Fact or data</i> The phenomena and facts are described in terms of properties and observable changes.	<i>Interaction</i> The properties of the bodies and the phenomena are understood as a relation system of interactions
Ways of reasoning	<i>Monoconceptual</i> It is assumed that the phenomena depend on only one variable	<i>Pluriconceptual</i>
	<i>Non systemic</i> The mutual effects among the involved elements are not considered.	<i>Systemic</i>
	<i>Reduccionist</i> More attention is paid to the properties than to the functions of the elements involved in the phenomenon.	<i>Non reductionist</i>

Table1. Characteristics of intuitive knowledge and science knowledge. Associated ways of reasoning.

In relation to the second item, information obtained in the longitudinal research allow us to hypothesize that *during the learning of the models of science, the students' ways of learning change from absolutely intuitive ones (in which not only the implied variables in the perceptive process or the interactions between them are taken into consideration), in which some interactions that happen among the different variables can be partially recognized. These "intermediate models" would be at the basis upon which a coherent conception with the model of science is finally built ( a model that meets systemically all the variables and interactions school science proposes for the understanding of vision).* Thus, and considering what has been proposed by Pozo y Gómez Crespo (1998), the first important ontological and conceptual change that would occur during the learning process implies thinking on the phenomena in terms of state and facts or of data to processes and multiple linear causes. These changes would also be accompanied by a progressive process of

overcoming naive/ingenuous realism that characterises intuitive knowledge. Figure 1 describes and exemplifies the ways of learning that would be built during the learning of vision.

<p><b>Category I</b> Completely intuitive way of knowing</p>	<p><i>Characterization of the conceptions:</i> The perceptive phenomena are explained in terms of observable facts and through information provided directly by the eyes. <i>Underlying principle:</i> State – Fact or data – Naive/ingenuous realism. Non-systemic, monoconceptual, reductionist reasoning. <i>Examples:</i> Objects are seen because we have eyes and look at them.</p>
<p><b>Category II</b> Intuitive way of knowing</p>	<p><i>Characterization of the conceptions:</i> Causal linear relations between variables are identified. <i>Underlying principle:</i> Simple linear cause – State – Naïve/ingenuous realism – Non-systemic reductionist reasoning <i>Example:</i> In order to see the objects, light must illuminate them and we must look at them with our eyes.</p>
<p><b>Category III</b> Intermediate way of knowing. Correct but incomplete</p>	<p><i>Characterisation of the conceptions :</i> Interactions between light and matter are recognised as the cause of perception while a more passive role is assigned to the visual system (to see). Incomplete but correct ideas are used in the school science. <i>Underlying principle:</i> Multiple linear cause – Process – Overcoming process of the naive/ingenuous process – Non-systemic pluri- conceptual reasoning. <i>Examples:</i> Objects are seen because they diffusely reflect part of the light that falls upon them as we look at them.</p>
<p><b>Category IV</b> School science way of knowing</p>	<p><i>Characterization of the conception:</i> light – object (reflection) and reflected light – visual system (perception) interactions are identified. Abstract models are used to understand and explain the perceptive phenomena. <i>Underlying principles:</i> System – Interaction – Overcoming of the naive/ingenuous realism – Non-reductionist, pluri-varied, systemic reasoning. <i>Examples:</i> We see because light diffusely reflected by the objects enters and stimulates our visual system.</p>

Table 2. Characterization and examples of the ways of knowing verified in a longitudinal exploratory research.

The research presented in this work was carried out to search for concrete data that would allow us to evaluate the proposed hypothesis, and then to reach a conclusion about how students learn and what sort of processes of change take place during learning in the **process of vision**. The main **objective** was to analyze, describe and interpret learning as it was experimented by a group of students of secondary education (13-14 years old) when the learning process was guided by a new teaching methodology, which tried to favor an ontological, epistemic and conceptual change as the one in figure 1.

The teaching methodology, which has been meticulously described in Bravo, Pesa and Pozo (2008) is characterized by the following steps:

- Approaching gradually and in an interdisciplinary way a model coherent with the scientific one that could explain that: “when light falls upon an object, this, according to its nature, absorbs light with certain characteristics and reflects with others. The light reflected interacts with the visual system of the observer stimulating selectively the photosensitive cells, so that light energy turns into electric pulses that are carried to the brain, where, through complex psychological processes what is seen is interpreted”.

- Presenting initial activities that allowed for the starting of the teaching-learning processes with simple everyday phenomena that could be explained with the students' own ideas. The objective was to guarantee a moment for students to build their own conceptions explicitly and to recognize their characteristics and nature, as they constitute the starting point for the construction of the new ideas.

- Gradually incorporating the study of increasingly complex phenomena that can allow students to recognize the existence of multiple variables on which vision depends (light, object, visual system) and to study the interaction processes occurring among them. First, light-matter interaction was analysed and then light-visual system interaction. The first one to be studied was light-object interaction because it is conceived that the model science proposes for that interaction seems more contradictory in relation to intuitive knowledge than the one proposed to explain light-visual interaction. It is known, however, that conceiving that light interacts with objects producing an absorption process and diffuse reflection would be of great complexity for students, as the functions of these, in terms of fact or data and/or simple linear causalities, meaning to explain that: "to see an object it only needs to be in the visual field of the observer" should not be taken into consideration so as to understand them in terms of multiple linear causalities and processes. It means to assume that: "light must illuminate the object and this reflect part of the radiation". But it is also known that these ideas would not be contradictive with the intuitive conceptions, but could broaden them by offering more specific functions to light and objects. However, the light-visual system interaction presents noticeable "contra- intuitive" aspects as it contradicts with everyday knowledge, which attributes to the visual system the function of seeing. The idea that light has to influence and stimulate the visual system so that to have vision would not only imply a "broadening" in the students' knowledge, but also a deeper change in the way the phenomenon has been conceived. So, once the light-object interaction was studied, the analysis of the interaction light-visual system could be started. Students were guided to acknowledge the fact that the visual system is stimulated when light enters the eye of the observer. The physiology and physiognomy of the human eye were studied and, in a simplified way, the processes that occur in the visual system (physical, chemical and biological changes that take place because of light stimuli). Finally, students were guided to conceive the light diffusely reflected by objects is the type of light that has to reach the eye and stimulate the visual system of the observer.

- Proposing an interrelated and recurrent approach of contents that might enable students to understand the vision phenomenon in everyday contexts by means of models, ways of doing and by acting with increasing coherence with what science proposes.

- Proposing problematic situations that allow students to apply and learn to apply the knowledge they have been constructing, with consistency and coherence to different context and situations.

At the same time, since the learning of sciences does not imply just to understand the explicative model it proposes, other especially designed instances were implemented so that students could:

- Recognize scientific knowledge as an alternative way of learning that could be helpful in the explanations of a variety of situations and to learn to apply it with consistency and coherence. The relevance of this instance lies in the assumption that learning does not imply the substitution of conceptions, so that the initial ideas and the ones built through instruction can co-exist in the mind of the student. The teaching proposal should help the student perform consciously and with criteria according to the context and the requirement of the problem.

- Be conscious and reflective in regard to the experimented learning process through instruction and to what the learning of sciences implies. This moment is decisive because, as Bachelard (1985) says "there is no science but for a permanent school" , so it is important that instruction will help

the student develop a critical attitude about his/her own learning process, knowing what he/she has learnt and how he/she has learnt, so as to be able to distinguish which tools he/she should use to keep on learning.

The designed activities, which integrated the teaching proposal, were varied and involved students and teachers, working individually and in groups; pencil and paper activities, experimental activities with the interaction of the teacher and the group through experimental activities, explanations and problem solving situations. These activities have been organized in four teaching stages that are presented, described and characterized in table 3.

<b>Stages</b>	<b>Strategies – Didactic objectives</b>
<b>Starting</b>	Motivate the student to explain his/her own ideas. Motivate the student with the content through the presentation of different problems. Clarify and interchange previous ideas, showing validity limits and limitations.
<b>Information</b>	Explicit the variables, relations and interactions among concepts when presenting the vision models. Present the proposed models from school science in a related and integrated form. Analyse the potential of the scientific ideas to solve and give answer to the proposed problems. Stimulate active participation and the constant stating of difficulties and doubts. Stimulate explanations to solve a variety of situations using the already constructed ideas. Teach explicitly the characteristic procedures of science. Mention the nature and construction of the scientific knowledge and perspective of ideas.
<b>Application</b>	Help students use their new ideas in different situations. Encourage students to evaluate their ideas, develop and apply them to explain the study of phenomena.
<b>Synthesis and conclusion</b>	Synthesize and evaluate the change in the ideas. Evaluate the potential of the new ideas. Promote opportunities for becoming aware of the experienced learning process and for reflecting critically throughout instruction and about what the learning of sciences implies. Promote new open questions to motivate students to keep on learning.

Table 3. The sequence of activities.

The designed proposal was implemented by a teacher whose main task was to guide the learning process, and he/she was responsible for presenting the school science ideas by teaching explicitly the characteristic procedures of science while raising the students' interest and curiosity and by helping them to be conscious about what they think, challenging them to test, develop and apply those ideas to explain everyday experiences. The teacher also called the students' attention to the ideas that emerge at different stages of instruction to help them build new ones, to apply them to new contexts, and to be conscious of the learning they have experienced so far.

Starting from the implementation of the described teaching proposal, the experienced learning of the students was studied in relation to the models that school science proposed to explain the process of vision. The “what” and “how much” students learnt was analysed in other studies (Bravo, Pesa y Pozo, 2008 1a; Bravo, Pesa y Pozo, 2008 1b). Here, the study about “how” they have done is presented and in order to do it, the students’ ideas are analyzed at the different stages of instruction, that is, at the starting, development, application, and conclusion activities.

The students’ conceptions are studied before a formal application of the topic at the starting activities. Starting from development activities, the students’ conceptions used in different contexts for the application of the model they have built during the teaching process, are studied. This is carried out after the teacher has introduced the idea of school science. The conceptions students used immediately after instruction have been studied along the conclusion activities.

The type of explicative model each student develops is studied at these stages and then there is an evaluation about how these models might change as the designed proposal is being implemented. This analysis aims at detecting the progress in the ways of learning students use to conceive the perceptive process from an intuitive knowledge to one that is more coherent with school science.

### **Research methodology**

In this case study the following design is implemented: pretest – intervention – posttest using a qualitative methodology. This allows for a detailed description (with the inference of the used models and the ontological, epistemic and conceptual principles as well as the ones related to associated ways of reasoning) of the conceptions students use in the different moments of instruction, and how learning changes because of the formal education process.

### **Participants**

The designed teaching proposal was implemented at Instituto Monseñor Cáneva in the city of Olavarría (Argentina) in the *Area of Natural Sciences* in approximately 80 hours of lessons. The students belonged to the 2<sup>nd</sup> year Compulsory Secondary Education (13 – 14 year- old students) and there were 32 in the group. The teacher in charge of the group and of the implementation of this proposal was a Physics and Chemistry teacher (university graduate), who was eager to participate in the project. His degree (and other works done with him in other contexts) allows us to rely on his solid and updated scientific and didactic experience, as he knows and shares the underlying theoretical principles of the most recent teaching-learning models. However, due to the principles of this proposal, various experiments have been carried out before and during its implementation. Before the teaching process started, the didactic-scientific basis underlying the proposal were studied, and the teacher was oriented to reflect critically on his own conceptions. During regular meetings, ideas were analysed and discussed, not only the ones students used but also the teacher’s work, trying to perceive what aspects could help students more adequately in the interpretation of the proposed models, as well as those that should be worked again, improved and/or deepened.

### **Data analysis**

The first analysis of this work consisted of a detailed study of the written answers students gave to the different problematic situations in the different teaching-learning stages. To include the answers in one of the pre-established categories presented in figure 2 (or in a new one that could be defined with the explanations students elaborate) the variables (light – object – visual system) and interactions (light – object: absorption, reflection; light – visual system: perception) to which students paid attention were evaluated at each stage of the analysis. So, answers like “I see because I have eyes” or “I see because the object is in my visual field”, were included in category I.



Answers like: “We see because there is light and we have eyes” were included in category II to which underlies an idea that leads us to suppose that seeing is enough if the object is illuminated and the observer looks at it. When the answers were “we see because the object reflects part of the light that reached it”, they were included in category III, which implies to suppose that seeing is enough if the object reflects light and the observer looks at it. Here it is conceived that the most relevant interaction in the process of vision is light-matter interaction. Finally, answers like “we see because light reflected by the object interacts with our eyes-visual system” were grouped in category IV, which is the one underlying school science.

Taking into account the mentioned analysis, each student was given a chart/diagram to represent the shared explicative model. Since students not always used the same mode of learning to explain phenomena in an activity, it was established that the model they used was shared in at least by 60% of the stated problems.

Once the way students have used to explain the phenomena in the different instances of analysis was detected, the changes they went through during the teaching process could be studied. The second analysis was carried out to verify which of those experienced models of change the students had more frequently used. Based on them, the ways of learning implemented by the students were inferred, as the conception of the perceptive processes had changed from an intuitive knowledge to another that seemed to be more coherent with the one of school science.

### **Tasks and procedures**

Questionnaires with problems with known and easy to understand situations were used to obtain information that allowed for the characterization of the knowledge students use in the different stages of instruction. Some of them questioned students directly about why we see the way we do it while others implied the use of the students’ ideas to explain and predict situations. In this task, students were asked to “present answers as complete as possible using their own ideas with respect to vision”. To come up with these questionnaires, the results obtained in the exploratory longitudinal research work were used, and that seemed to evidence, among other aspects: the type of phenomenon that is most adequate to present as well as the best way to write the instructions in order to get the most complete possible explanation; the number of items to include taking into consideration how complex it is for the students to develop their answers (Bravo y Rocha, 2006); and, in relation to it, how self defeating it is to include too many instructions because of tiredness and of the fast loss in the attention span that can make students quit some questions without answering and/or to present too short explanations. In order to infer the underlying conceptions with confidence, strictness and reliability, students were always instructed to present the most complete possible answers.

Starting activities required students to explain what elements were involved in the process of vision and which of the interactions among them they could recognize. In the development activity, students were asked about what elements they considered as in this process, and what “function” they had in the process of vision. The answers allowed for the evaluation of which of the elements (light, object, eyes, visual system) and processes (illumination, absorption, reflection, perception) students considered explicitly associated to the studied phenomena.

This activity was carried out when the contents related to nature and light spreading and the interaction between radiation and the different bodies had been introduced (absorption, transmission, diffuse reflection). To do the task, the students had to take decisions about the conditions that had to occur for seeing the objects clearly, so that they were able to tell, according to their own ideas, if a body would be seen or not under certain observation conditions and then they would come up with explanations about what they already knew about the phenomena. The

conclusion task was answered immediately after the end of the teaching process (this was considered an evaluation activity by the teacher). In this activity, students had to solve “new” situations (which had not been analysed in class) and others that had been already answered in the starting activity. The aim of this activity was to have students evaluate their own initial answers and to have learners complete and/or modify them if necessary and, based on it, to have them think about their learning experience.

In the appendix, some examples of the questionnaires used are presented.

## Findings

In the *starting* stage, before the teaching proposal was implemented, all students involved in the study explained the process of vision in an intuitive way, using a non-systemic and reductionist way of reasoning.

83% of them explained that “we see because we have eyes”, what means to use a conception as the one represented in figure 2, which can be characterized by states of ontological, epistemic and conceptual principles, a well as by naive/ingenuous realism and fact.

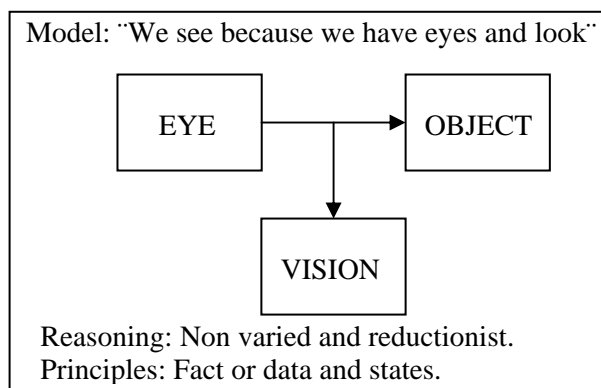


Figure 2. Completely intuitive model.

However, 17% of the subjects used the explicative model represented in figure 3, which implies that to explain, “besides looking at the object, light has to illuminate it”. This conception can be characterized by state principles, ingenuous realism and simple linear causality.

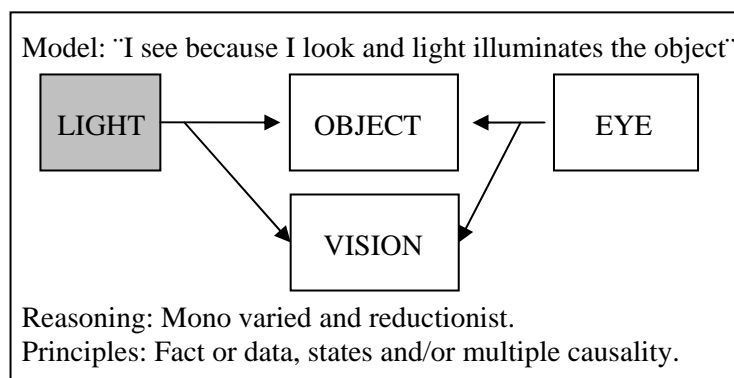


Figure 3. Completely intuitive model based on simple linear causalities.

In the *development* stage most students already recognized light as an essential element for seeing (and not only the eyes that allow us to see). So, 60% explained that in order to see light has

to illuminate the object, which implies the use of the associated way of reasoning presented in figure 3.

On the other hand, 42% of the students explained the process of vision assigning to light the “role” of illuminating and also to interacting with the objects through the process of diffuse reflection. They attributed a passive role to the visual system, the one of looking at the object. This conception (represented in figure 4) is correct but it is considered incomplete in the context of school science. Because of that, it can be characterized by the conceptual and ontological principles and multiple linear causality.

Only an 8% of the students used the completely intuitive idea represented in figure 2 at that moment of instruction.

In the *application* stage most of the students used models that were coherent with the ones of science. 42% explained that in order to see, “the observer has to look at the object that reflects diffusely part of the light that falls upon it” (figure 4). Another 42% explained the process by paying attention not only to the interactions that occur between light and the objects, but also to the ones between the reflected light and the visual system (as it is shown in figure 5). The conception shared by them (that corresponds to the one of school science) would be characterized by ontological and conceptual principles of system and interaction.

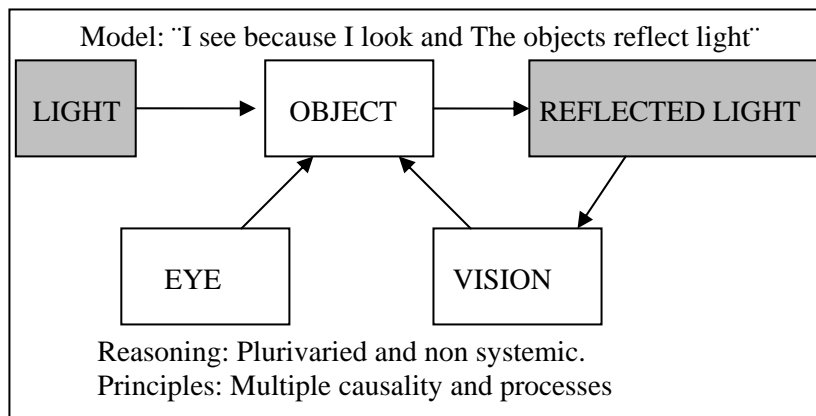


Figure 4: Correct idea but incomplete in the context of science.

The percentage of students that still use intuitive ideas in this stage (figures 3 and 4) can be considered low (17%).

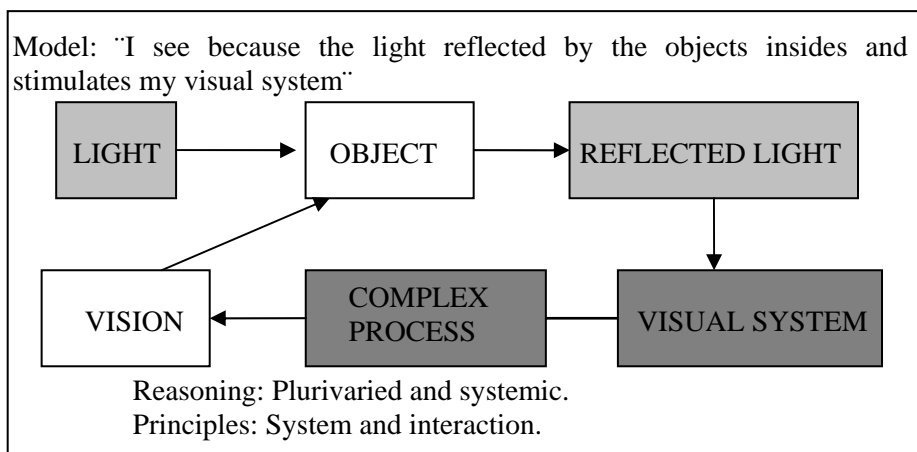


Figure 5: The school science idea.

Finally, in the **conclusion** stage, 83% of the students used the conception suggested by science (figure 5) and the remaining students used the “correct” but incomplete model (figure 4). That means that, at this stage, none of the students used intuitive ideas such as those shared previous to instruction.

In conclusion, as instruction goes on, the models shared by most of the students gained complexity, systematization and abstraction on a progressive process of approximation to the characteristic way of knowing of school science.

Although all students go through a far-reaching change that tries to explain the phenomena involved in facts-data and states to multiple linear causalities and processes or systems and interactions, not all of them seemed to have experienced the same transitions between conceptual and ontological categories and even less between the same instances of analysis.

When analyzing these changes experienced by most of the students, it could be observed that four of them appeared as the most representative and significant:

- The change in the explanation of phenomena from completely intuitive ideas considering the eye as the essential element for being able to see; to the conception that it is necessary for light to illuminate the object. 33% of the students experienced a change in the way of learning by going from mono conceptual reasoning to another one based on simple linear causalities. This change is presented in figure 6.

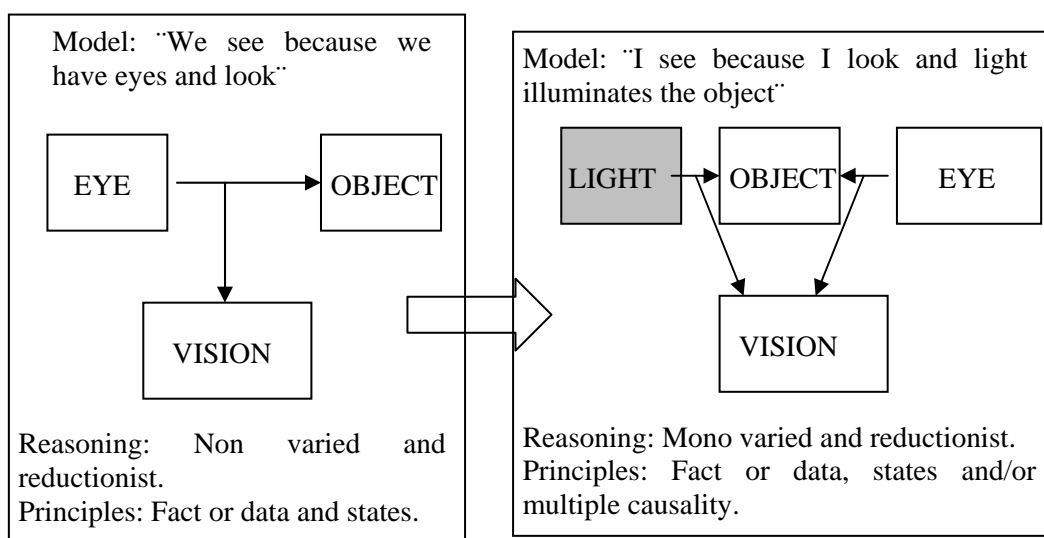


Figure 6: Change in the way of knowing: from the state and data to a linear causality.

- 33% of the students, who that previously used a monoconceptual and reductionist reasoning, guided by the everyday knowledge and based on ontological and conceptual principles of fact or data and state, have turned to a more coherent way with the school science one that explains the phenomena in terms of multiple linear causalities and processes. It takes into account abstract models that conceive the “no intuitive and invisible” interactions that are produced between light and matter. With this change (figure 7), students incorporated simultaneously light and objects as variables to explain the process of vision. In this “new” conception, they have been given more active roles, while light not only has to illuminate the object but it also has to interact with the object, absorbing and reflecting diffusely part of the radiation that has reached it.

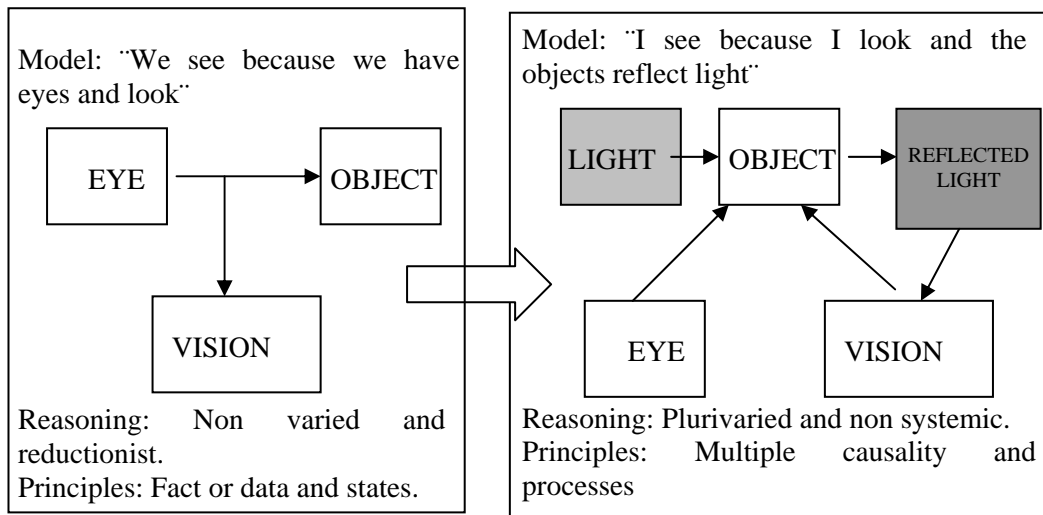


Figure 7: Change in the way of knowing: from simple causality to multiple processes.

- The change in the conception of vision in terms of an intuitive idea to one coherent that is coherent with the one of science. This change, represented in figure 8, was experienced by 25% of the students. It implies the incorporation of the object as a variable to explain the process of vision (adding to it the eyes and light that were previously known) and were ascribed active roles as it was conceived and explained by using the abstract models of science, light-object interaction.

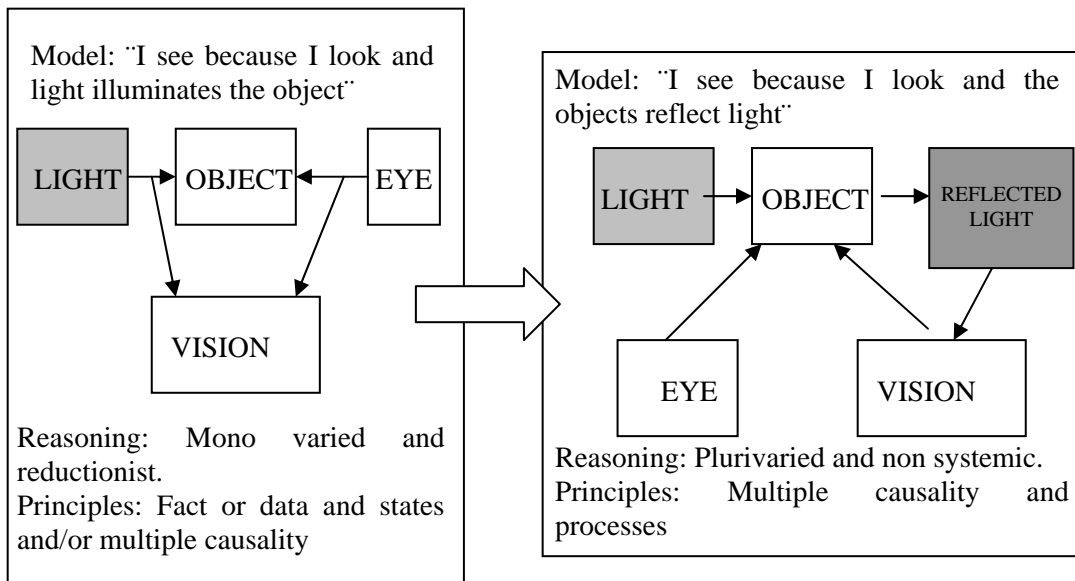


Figure 8: Change in the way of knowing: from linear causality to the systems of interactions.

- 58% of the students experienced a change in the conception of the process of vision from diffuse reflection, which occurred in the interaction between light and the object, to the product of multiple interactions that included not only light-object interaction but also reflected light and visual system interaction. Figure 9 represents the observed change.

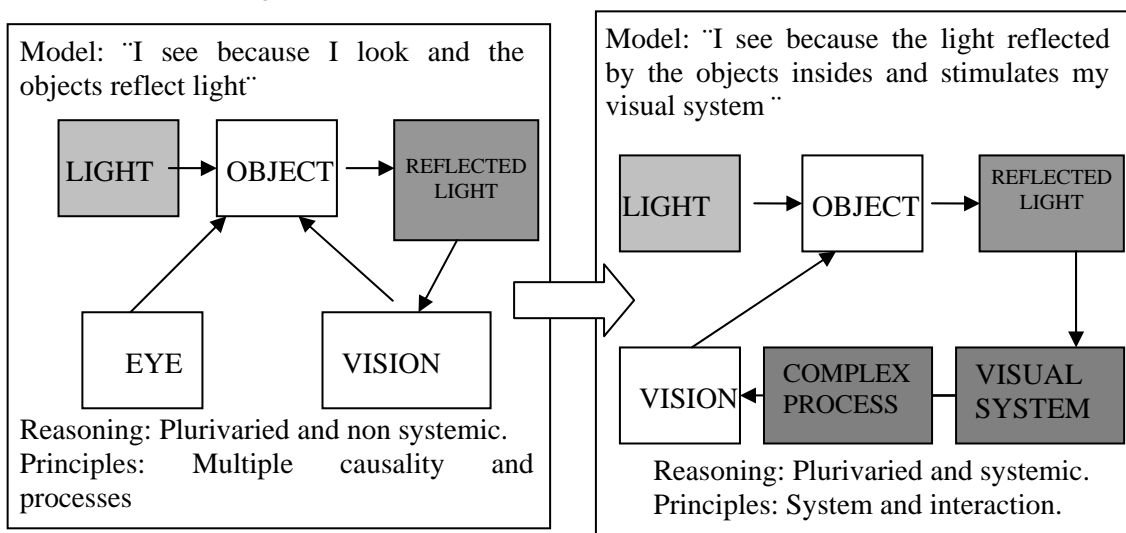


Figure 9: Change in the way of knowing: from multiple causality and processes to the system of interactions.

Finally, the changes that occurred with less frequency could imply conceiving the process of vision from completely intuitive (figure 2) or through relations of simple linear causality (figure 3) to school science conception (figure 5). These changes were represented by the 8% and 17% of the students respectively.

These results may help to conclude that during the learning process, students tended to gradually incorporate in their explanations the different elements involved in the process of vision, and then to integrate them as: light and objects (through the illumination process or reflection) and light reflected-visual system. So, at the beginning, students tended to explain the phenomena in purely intuitive terms. Then, most of them started to recognize the importance of light in the process of seeing, or they started directly to use a coherent model with the one of science although it was incomplete, through which, great importance was given not only to light but also to the object and the interaction between them. Finally, most of the students built the model of school science when they started to construct a more complex and complete model "correct but incomplete" represented in figure 4.

### Concluding remarks

In the introduction, a hypothesis was proposed in which learning the models of science would imply a gradual process, during which "intermediate" ways of knowing could be built between the knowledge initially shared by the students and the one they were supposed to build with the help of teaching. So, based on these "intermediate" models, students would build a way of knowing significantly coherent with the one of science.

In relation to that, it was proposed that the change in conceiving ontologically the phenomena in terms of states to a conceptualization of them as processes would imply a relevant first change in the learning of science. This means establishing relations among the concepts. The subsequent complexity due to teaching this way of knowing, would imply the understanding of the relations in terms of systems, the way science does it. Concerning to the conceptual component of accepting the different phenomena as facts or data, would turn to relate them, at the beginning, to some given processes of linear causality, based on simple, unidirectional diagrams. These linear causality analyses could gain complexity, as more causality factors would be added, going from a single one-factor causality to multiple causality in which various causes have been added. This is to finally manage to understand and interpret these phenomena in terms of relations of interactions in a

specific system. Added to these changes, would be the overcoming of the epistemological principle of naïve/ingenuous realism, which could give way to a new perspective, which would imply to assume that to know is to construct and use alternative models to interpret the world that surrounds us.

Taking this into account and the teaching proposal, it seemed possible to gradually approach the model of science, which meant to use, at the beginning, the interaction light-matter, and then light-visual system so as to finally join them in a unique model, the one of school science. This sequence was based on two premises. The first implied to assume that the model science intended to explain the interaction light-matter would be less complex for students than the interpretation of the relative model of the light-visual system interaction (as the first one implied a broadening but not a contradiction of its intuitive knowledge). The second premise implied to supposing that the construction of an “intermediate” model between the intuitive and everyday knowledge, while paying attention not only to the interaction light-matter to explain vision would help learning because it would be at its basis. Learning that the visual system reacted in the presence of light and would help students construct the school science model more significantly.

The obtained data allowed the authors to corroborate the proposed premises. In that sense, the first model built by students has made us explicitly consider light, in the vision process, with the function to illuminate, as the object and visual system have passive roles. The building of this idea implies a first change in the ways of reasoning; changing from the ones based on facts or data and states to others more complex based on simple linear causalities (light illuminates the object, the eye looks at the object). In an intermediate stage between these intuitive models and the one proposed by science, students tended to build another model that suggest that we see because the object reflects diffusely part of the light that falls upon it. In this model, object and light have an “active” role in the process of vision, and the visual system continuous having a passive role: the one of “looking”. From this conception, light stops having the only function of illuminating the body so that the eye can see it. This simple causality turns into a multiple one as it is interpreted that light falls upon the object and then reflects itself. That is to say, the object has a role that goes further than “it has to be there, otherwise nothing would be seen”. Most students managed to build the model of school science by using as a “platform” this “intermediate” model.

Besides, the findings allow us to know that the building of models of science in relation to light-matter interaction can present less complexity for the students than the interpretation it proposes in relation to light-visual system interaction. Data obtained would reveal that most of these students have incorporated apparently quite “easily” the interaction light-object to their explanations. One of the first observed changes (that has been experienced by 60% of the students along the instruction) implied a change in the conception of vision, from intuitive terms to light reflected by the objects. While the interaction light-visual system seemed much more difficult to be accepted by the students, as it is shown in the “application” stage, because a high percentage of students did not seem to be able to share the idea of school science, even when between this stage and the “development” stage, multiple and varied activities for studying the functioning of the visual system and their interactions with the light reflected by the object had been already practiced by the students.

As a final thought, it seems possible to conclude, in accordance to what was proposed by other authors (such as Delval, 2004; Galili y Hazan, 2000 y Pozo y Gómez Crespo, 1998) that learning the scientific way of knowledge of science is a gradual process (and not a sudden or revolutionary change), which implies the building of ways of knowing increasingly more complex and coherent with the one of science.

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## Appendix

### **Starting Activities:** “Our Ideas”

1. - Explain what happens when you see this sheet of paper. Based on your idea about how we see, explain as completely as you can. Support your answer with a drawing.

2. - Why does vision get poor if: **a)** you turn off the lights in a room? **b)** You close your eyes? Justify your answers in the **MOST COMPLETE AND DETAILED** way as possible.



Could you explain to me why I can see him and he can't see me?

3.-

4.- My teacher told me that for seeing any object I need light, eyes and obviously there is the rose. I can understand the importance of the light (that will help me illuminate the object) and the eyes (that will help me seeing it), but I don't understand what is the role played by the rose in the process of vision. I don't understand how the rose relates itself to the light that falls upon it and to my eyes that look at it... **Could you explain that to me?**

### **Development Activities :** “Your ideas, my ideas, our ideas ...about the process of seeing”

1) What has to happen so that you can see the objects that surround you?

2) What would you do to stop seeing that leaf? Give at least three alternatives.

3) Discuss your answers and those of your classmates. Now answer the problem again using the ideas shared by the group.

4) Answer the following questions:

**a)** “Which is the role of each of the elements you believe take part in the process of vision in the act of “seeing”?

**b)** Choose any object and, with a drawing, represent how each one of the mentioned elements acts when you see the chosen element?

*To answer these questions, you can analyse all the experiences that are stated in the problems and try to come to an agreement. If you don't reach one, write down the differences. Justify each answer and explain the process you went through during the experience.*

### **Application activity:** “The process of seeing...”

1) Using your idea about how we see, explain why if you cover that sheet of paper with a cardboard you stop seeing it, while if you use a transparent sheet you go on seeing it.

2) Use your idea about how we see to answer the following questions related to the situation shown in the drawing. Represent your answers in a diagram.

**a)** Where would you place the source of light so that grandpa could read clearly what his grandchildren had written to him? Why?

**b)** Taking into account the source of light in the place you have placed it: Could some of the children see what is written? Which one? Why?

**c)** Taking into account the source of light in the place you have placed it: Could the youngest boy see what is written? Why?

**d)** What would grandpa see were the sheet made of nylon? Why?

**e)** The boy using the headphones says he can't see the sheet. Which do you think could be the reasons for this to happen? Give at least two reasons that allow you to justify the fact that this child can't see the sheet.

*You can imitate the situation, if this helps to elaborate your explanations.*



**Conclusion Activity:** “What and how we learnt?”

1.- Re-read the answers you written in the activity “New ideas” that were done while analyzing the topic together. How and why do we see as we see?”

2.-

- a) Taking into account all that you have analysed up to now, tell us whether you would change any of them.
- b) If you decide upon any change, give your new answer.
- c) Compare your initial and final answers: What is your conclusion about the learning you have experienced?
- d) Do you think it was relevant to the study of the topic “how and why do we see as we see? Justify your answer.
- e) Give your opinion about the way these topics were developed. Write about the aspects that have helped you most in learning about the analyzed topic and the ones that have not helped you much. Don't forget to justify your opinion.

3.-

- a) In terms of shared ideas up to this moment, give ALL the conditions that must happen so that Sofia is able to see what Juan is writing.
- b) Explain and represent in a diagram the process through which Sofia SEES what Juan has written.

