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THE USE OF THEORETICAL MODELS IN SCIENCE TEACHING. THE 'PARADIGMATIC FACTS'

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ABSTRACT

In this paper we explain a proposal of epistemologically based didactic action, in which "teaching to explain theoretically" is considered to be a priority.

1. INTRODUCTION

Science philosophy has undergone an authentic revolution in recent years. The collaboration between science philosophers and historians has resulted in the emergence of different models of scientific growth and new thoughts about what a scientific theory is, in which both "the justification context" and the "discovery context" of same are taken into consideration. These new ideas are extremely useful for the didactics of science and permit the elaboration of models to interpret the emergence of scientific ideas in the classroom. These models in turn direct educational intervention and allow innovation in the didactic field.

In this paper the contribution of the semantic model for scientific theories (Giere, 1991) to the didactics of science is analysed. We believe that this conception of "scientific theory" is extremely useful and that it suggests new didactic performances. There are two types of these:

1. To emphasize the importance of knowledge of the "real world" to significantly proceed with its modelling. Consequently, we must insist on the need to convert experimenting into the centre of the science class, but in a somewhat different way from what has been done till now.

2. To use "evolutive theoretical models" adapated to this real (experimental) world built in the class and which will therefore be different from those used by scientists. As the pupils have access to a smaller number of "facts" than those which the scientific theories of each one of the disciplines contemplate, the theoretical models must be simple and get more complex as they learn of new facts to explain.

2. WHY A SEMANTIC MODEL FOR SCIENTIFIC THEORIES?

One of the main problems of teaching science is that it is both experimental and theoretical: it interprets the world just as the experiments show it to us, it does not limit itself to describing it. The language with which science refers to the world is a theoretical language and it must be decoded to be able to recover its experimental meaning.

2.1. The problem of the emergence of meanings in the classroom and in the scientific community

It has been stressed repeatedly that science teaching must be experimental, but a lot has also been written about the relative failure of school practice. One of the most important and unanimous criticisms refers to the lack of global sense of school experimets for the pupils and their disconnection from other activities of scientific formation (Woolnough, 1991).

The current analysis on the historical evolution of science has also demonstrated the complexity of the process which finally permitted "experimental science": not only must we speak about the construction of theories related to experiments, but also of the social and conceptual construction of the same "experiment". Only an experiment constructed in this way becomes a source of argument in relation to the theory. In this paper, we make a proposal which permits the pupils to equally use scientific theories with some meaning in their own experimental world.

We can speak of construction of knowledge both in the science classroom and throughout history. In both cases the knowledge acquired enables one to explain "in a theoretical way" in writing. Nevertheless, the two processes are very different. The teacher must elaborate the sciences to suit the pupil, so that he/she may understand the most important part of them. In this process of "didactic transposition" the teacher must act according to a "science model" and a "teaching-learning model". And the final concretion of "classroom science" is a didactic creation with the aim of educating the scientific mentality.

The meaning of scientific theories is communicated, discussed and agreed by the scientific community, through the written documents which take shape according to certain arguments which are accepted as valid. In the same way, it will be necessary for the pupils to write about science to get to elaborate their own school science, they have agreed on.

2.2. The process of modelling the world

The changes in the philosophy of science from the sixties have produced new conceptions of the nature of scientific theories (the structuralist and semantic conceptions), which greatly modify the "syntactic conception" from the Circle of Vienna ("inherited conception"). These new conceptions consider both the synchronous and the diachronic aspects of science.

Giere's semantic conception is a cognitive approximation to the study of science and because of this, it seems particularly suitable as a "science model" to be considered in the process of didactic transposition, as it uses the models of knowledge proposed by the cognitive sciences and also the didactics of science.

According to Giere, science is constructed on the basis of contrasting the phenomena with "theoretical models" through the elaboration of "theoretical hypotheses", which make it possible to speak of the experiment in terms of the model and vice versa. The theories are a set formed by the "models" and the theoretical hypotheses. On accepting that the applications of the model are a constituent part of the theories, the connection between "the theoretical" and "the experimental" is ensured: the former only has meaning in relation to the latter. The theoretical models are linguistic systems whose characteristics are specified by a definition (an indication on how certain terms have to be used), whilst the theoretical hypotheses state that a given real system is similar to a theoretical model (which is part of an imagined system).

It seems that the mind works in a similar way in the process of making sense of the world. The establishment of analogies thus constitutes a self process of the dynamics of common knowledge, which is similar to that of interpreting processes through models. Then, this approach would seem promising. Didactic actions in all the areas of knowledge may easily be derived from it, particularly with regard to language which would take on a specific and valuable meaning for the teaching of all subjects (Izquierdo, 1992, a and b).

For the process of "modelling the world" to become useful in the science class, it is necessary that the pupils learn to regard the world in the specific way of science. This requires a very careful didactic action, which must begin by establishing (and partly constructing didactically) that the more one inspects the physical and biological world; and what is searched for in it:

the regularities which permit a simultaneous interpretation of groups of phenomena, the better.

2.3. Paradigmatic facts

Experimental practice is indispensable. Nevertheless, we know that this is very difficult and it is currently accepted that the approach to said practice should be thoroughly re-examined, to make it coherent with the new didactic paradigms. Frequently the pupils work in a routine way in the laboratory, without putting into practice hypothetic-deductive thought which is peculiar to experimental work (Friedler and Tamir, 1990) Hodson, 1990).

In our proposal we consider that the scientific experimental fact must be "constructed" in the class, so that it may be meaningfully manipulated by the pupils in relation to the conceptual setting (the theoretical model) which is introduced. The pupils must be able to "take possession of" phenomena they can relate to others that they already know and about which they ask themselves questions which interest them and which are relevant. In the same way, the history of science teaches us that it was necessay to "construct the experiment" throughout a long historical stage to be able to produce experimental scientific texts (Shapin and Schaffer, 1985).

From all of this a " model for experiment in the science class" emerges which is particularly suitable for using theories which significantly include some facts of the real world. This model has hardly any relation to either the classical "laboratoy practices" or scientific experimentation. In our curricular proposal we have opted for providing the pupils with new instruments (e.g. an air pump or windmill) so that they may build "facts" with them that are going to be studied and that they will have to learn to explain . A fact that can be creatively manipulated and which will be explained by means of a theoretical model constitutes a paradigmatic fact and it is the first theory proposal that the pupils must master.

This type of fact can function as an analogy for other phenomena which are different but related. In this process some details of the theoretical model must be modified as well as those of the theoretical hypothesis, and because of this the theory has developed but it has not changed radically. Some sequences of "evolutive theories" may be designed which lead progressively towards a scientifc view of the world: quantitative and humanising (Izquierdo et al., 1992).

3. A RESEARCH IN THE PRIMARY SCHOOL

The research we present refers to a classroom experiment which lasted three months, referring to the subject "Air - what is it? and what does it do?". The didactic unit which was carried out belongs to the Curricular Project for the obligatory secondary stage "Sciences 12-16" designed in the Curricular Area of the CDEC, of the Generalitat de Catalunya (County Council) (CDEC, 1991-3).

3.1. Presentation

The pupils made several experiments on the air with the help of a manual apparatus to decrease pressure, which was specially designed to allow the pupils to be able to manipulate gases . They were able to design several experiments for themselves with this apparatus and this seems very important to us, considering that the phenomena studied were significant for them. We intended to teach the pupils to explain the experiments with a model: the "gas model" as a set of particles which move by chance and the model "apply pressure"; both models make sense of a relation between the variables.

The Gowin Vee (Novak and Gowin, 1984) was used throughout the whole of the didactic intervention to guide the explantion towards the relation between the "fact" and the "models" and our analysis was centred on the pupils' Gowin Vees, which they produced from the experimenting and discussion in the class; they chose the concepts for this and redacted the "principles" and the "conclusion" freely. The Gowin Vees that they developed were representative of their own way of thinking and permitted a very rich discussion in the class.

3.2. The representation of the pupils' conceptual system, as an indicator of their theories

From our analysis we were able to represent the conceptual system shown by the pupil in the Vee frame, or in another type of redaction. For this purpose we made a conceptual map in which the grading of the concepts they chose in their explanation (due to the class relationship or part of it) was shown as well as the relation between them due to a theoretical rule or property (Thagard, 1992).

Following Thagard's proposal, we consider that the differences in the maps demonstrate the differences in the theories. On comparing the maps, we were able to identify and characterize the differences in the pupils' theories and we can also justify a didactic intervention with regard to this difference.

A. Different explanations for one same experiment

Below we present three conceptual maps which are representative of the differences which were detected in the conceptual systems that the pupils' explanations were based on. All of them referred to the increased volume of a balloon which is inside a container when interior pressure is modified.

First case (See fig. 1)

The rules are:

R-1: The air wishes to expand

R-2: The vacuum separates the particles

R-3: The pressures tend to equalize

R-4: The greater the volume, the less pressure there is.

This pupil's explanation (the conclusion in the Vee) is: "on making the vacuum the balloon has increased its volume because the air inside wished to expand". We can see that this pupil had a conceptual system which is quite correct, allowing him to conclude with a realisation of the relations between the volume, pressure and quantity of air variables, nevertheless, on explaining the phenomenon he uses an ingenuous "principle" which he had not learnt in the class.

Second case (See fig.2)

The rules are:

R-1: The pressure of the air and of the balloon tend to equalize.

R-2: There is a relation between the quantity of air we remove and the increase in the volume of the balloon.

R-3: On making the vacuum, the pressure of the air on the balloon has decreased.

This pupil's conclusion is: There is a relation between the quantity of air we remove and the increase in the volume of the balloon. Once more this is a poorer explanation than one might expect, after the analysis of the Vee.

Third case (See fig. 3)

R-1: Air has a tendency to expand. The air inside and outside make a mutual effort because of its tendency to expand.

R-2: The pressures tend to equalize.

R-3: the pressure decreases if there is less air.

This is a very complete conceptual system, but in the explanation there is no explicit connection between the "tendency to expand" with the difference of pressure, although the connection is already on the map.

Other cases

We consider that a good explanation from the pupils, made on the occasion of the final examination, is the following: "When we put a balloon inside a pot without making a vacuum, it has a pressure (from above). On creating a vacuum, the pressure decreases because there is less air. Then the air inside the balloon tends to equal the pressure, because we have not removed the air from the balloon and to equalize the pressures, as the balloon is elastic, it expands. (Draws the forces). We must say that outside the vacuum pot the air also presses to enter and equalize the pressure, but the pot resists it and does not offer any transformation and/or deformation". This conceptual system is similar to case three, but the explanation is much better.

Another pupil presents the same conceptual scheme as 1 in his Vee, but in spite of this, his conclusion is different. The pupil simply concludes: "On making the vacuum, the balloon has increased its volume". Another pupil explains the phenomenon this way in his final examination: "When we make the vacuum inside the container, the air that was inside the balloon wished to occupy the empty space around it, which is why the balloon inflates. We must know that air tends to occupy empty spaces".

B. The explanations of one same pupil to different experiments with gases

The experiments the pupils carried out were: the increase in the volume of a balloon on decreasing the outside pressure, the tin which dents (wrinkles) on decreasing the pressure in its interior, a cooked egg which is inserted in a container on decreasing the pressure in it. The pupils had to explain what they were doing, draw the experiment, predict what would happen and explain what had really happened.

N. (See fig. 4 and 5)

<u>The tin</u>

She draws the tin, with the lid on. She predicts that the tin will swell. She describes what happens: the tin wrinkles slowly at the beginning and then faster. (At no time does she refer to the water which was put into it).

The conceptual system she manifests in her explanation is the following:

R-1: The air outside wishes to enter to occupy the empty space.

R-2: The air inside has contracted on cooling.

R-3: The contraction of the air leaves an empty space.

<u>The egg</u>

She draws the assembly and predicts that the egg will not penetrate into the container. She describes what happens: "the water boils and steam comes out. The egg begins to swell and enters the container. The steam has been dragging the air and a kind of empty space remains when it is covered with the egg and it is left to cool". In her explanation, the pupil reformulates R-1 and introduces new rules, besides using the other three.

R'-1: According to the theory of gas, the air outside wishes to enter to occupy the empty space.

R-4: The air has pushed the egg which prevented it from entering.

R-5: If the quantity of air is reduced, an empty space remains.

<u>The balloon</u>

The prediction is that the balloon will wrinkle. She describes what happens correctly and explains it with R-1 exclusively.

This pupil does not guess the forecast in any of the three cases, but she does not seem surprised and elaborates coherent explanations. This behaviour has been very frequent in the classroom where the atmosphere was expansive and the communication beween the pupils and with the teacher was very fluid.

M. (See fig. 6 and 7)

<u>The tin</u>

She draws it correctly and describes what she is doing, without forgetting that the tin is heated and that there is water inside it: "the air which was there has evaporated and only a little is left. The tin is covered and left to cool". She predicts that the tin will wrinkle. The explanation is:

"On closing the lid of the tin and turning off the gas (fire), the air cools and the particles join. The exterior air flattens the tin because it wants to enter the tin but cannot because the lid is on. The pressure inside the tin is different from the outside pressure. We can say that there are two kinds of pressure." We represent the conceptual system through the map in the fig. 6.

R-1: On heating the air evaporates and goes. (Confusion with what was explained to her about the water).
R-2: On cooling the air particles join (Ditto).
R-3: The outside air wants to enter.
R-4: It presses because it has nowhere to enter.

The egg

She draws it correctly and predicts that the egg will enter the container. She describes what happens: "the air inside has evaporated and gone out". In her explanation she uses the R-1 and R-2 rules. She reformulates R-3: The air outside wanted to enter because air had come out. And she adds other rules:

R-5: If there is less air, the pressure will be less.
R-6. If the pressure is lower, there is less force.

Her conceptual system, represented in the following map (fig. 7), has developed. The problematic aspect is in R-2 and could have been obviated if the variables-temperature and change in the state of the water had not been introduced into the experiment.

We can confirm that neither of the two pupils refers to the water we put in the tin and in the erlenmeyer. The same thing has happened with most of the pupils, who do not seem to need it for anything; some seem to remember something, but they apply the model "phase change" (the particles join on cooling) to the air, to justify the decrease in pressure.

3.3. Relation between the conceptual systems and the adaptation of the experiment

The analysis of the maps obtained in view of the different experiments indicates that there are significant similarities beween them, but also differences. The most important differences can be attributed to the inadequacy of the experiments in which water was heated, since the explanation requires the use of concepts and models not yet explored, which confuse the incipient consolidation of the one which was being worked on: these experiments introduce an unnecessary complexity and induce the inadequate relations which are shown on the maps.

The similarities are noteworthy and indicate that the theoretical model expressed by the maps is useful for the pupils and that they modify it introducing new rules when necessary, without contradicting the ones which had already been used once. The differences in the conceptual maps also show clearly that the facts explained by each one of them are not identical, because the regularities they find in them are different.

The most serious errors refer to:
- confusing the weight of the bodies with the pressure of the air around them (only one pupil);
- modifying the characteristics of the particles (they dilate) (three pupils).

The most frequent are due to attributing properties to the vacuum, to explaining the phenomena in terms of "wish to expand" and to confusing "volume of gas" (which they relate to quantity of gas) with "volumen of the container". We have seen that the pupils need three ideas to accept that the gases occupy the whole of the container: if we decrease the quantity of gas, a vacuum remains and the remaining air wishes to expand to fill it. A typical explanation for the swelling of a balloon would be: "When we make a vacuum inside the container, the air that was inside the balloon wishes to occupy the empty space around it, this is why the balloon inflates. We must know that air tends to occupy empty spaces".

3.4. The "fifth area" of the V

The coherence of the pupils' conceptual system should proceed from the compromise with the "gases" (of particles) and "pressure" models; nevertheless, we found that there are more subtle differences, both in the models and in the theoretical hypotheses. This should not surprise us, since the pupils are learning both the theoretical model and the elaboration of theoretical hypotheses. This is why we give great importance to what we call the "fifth area of the V", that is, to the lines of argument which constitute the conclusion, as it is in these that the differences are detected which finally will have to be agreed to make the explanation "socially accepted", in which, however varied the argumentary line may be, the relation between variables will have to correspond to different formulations of some same theoretical hypotheses.

We have been able to observe how some pupils have a suitable conceptual system to elaborate the conclusion asked of them, but they do not use it. It would seem obvious that this is something that should be explicitly taught: to think and to write are related activities, but they are not the same. It is a case of learning that some arguments are suitable for scientific explanation and others are not. Once more we find that is is the model which finally acts as a guide in this: as the pupils accept a mechanical model and not a biological one for the air, they will succeed in their decisions about which arguments to use.

It is this fifth area of the V which permits the planning of the later didactic action. The differences in the "interpreted fact" (the theory) should be discussed in the class, considering that, in this moment, the fact is included in the theoretical hypotheses that link it to a model.

4. CONCLUSIONS

To sum up all that has been stated, we must emphasize three ideas:

1. We believe that experimental facts must be constructed in the science class, as they were also constructed in the history of science from the moment that the development of experimental science seemed necessary. This construction requires a theoretical model which allows the discussion to be situated on what happens in the scientific context.

2.- The regularities between the facts, considered in relation to the model, constitute the theoretical hypotheses. With these, the fact is interpreted in terms of the model. This must be explicitly worked on in the classroom.

3.- The conclusion must be redacted in terms of theoretical hypotheses. These must be taught explicitly as the pupils disregard them easily to recover other lines of argument characteristic of previous models.

The analysis of the explanations elaborated by the pupils about the behaviour of gases seems satisfactory to us in three ways:
- because it seems to corroborate the holistic focus of the experiments, facilitating the autonomy of the pupils' interpretation;
- because it confirms the importance of the pupils "taking possession" of the phenomenon and of being capable of generating new facts for themselves;

- because it has achieved a satisfactory level of formalization in an atmosphere of interest in what was being done.

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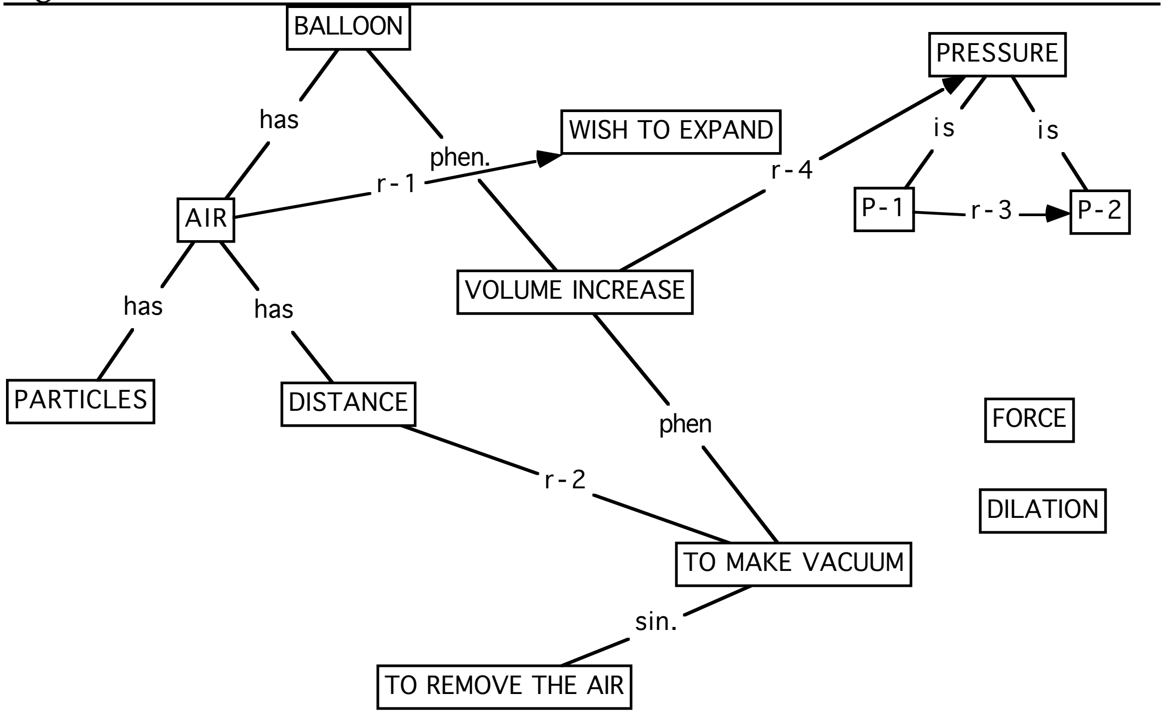
Fig. 1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phen.
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is
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AIR
P - 1
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P - 2
VOLUME INCREASE
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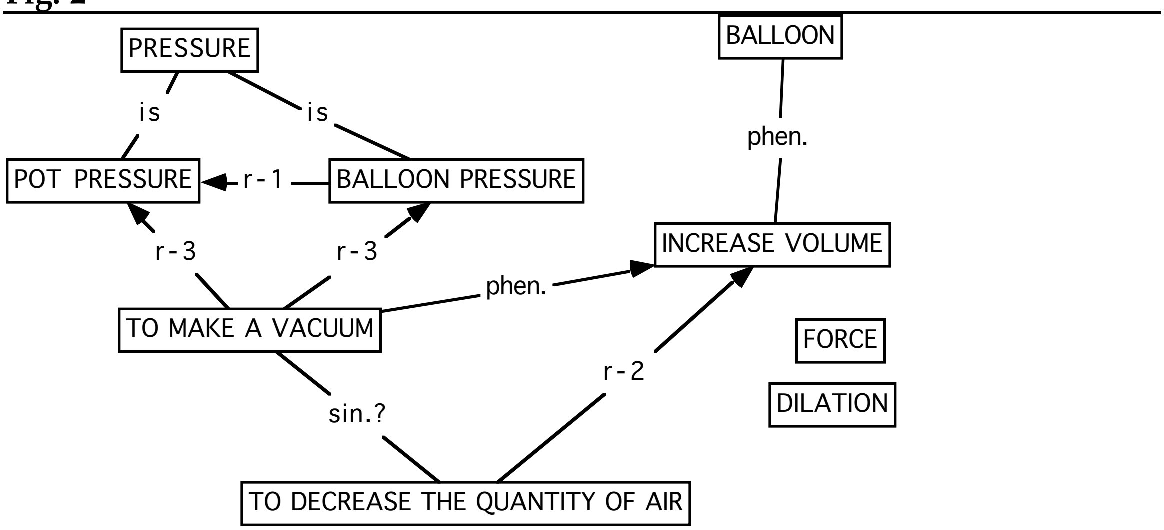
r - 2
DILATION
TO MAKE VACUUM
sin.
TO REMOVE THE AIR

Fig. 2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TO MAKE A VACUUM
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DILATION
TO DECREASE THE QUANTITY OF AIR

Fig. 3

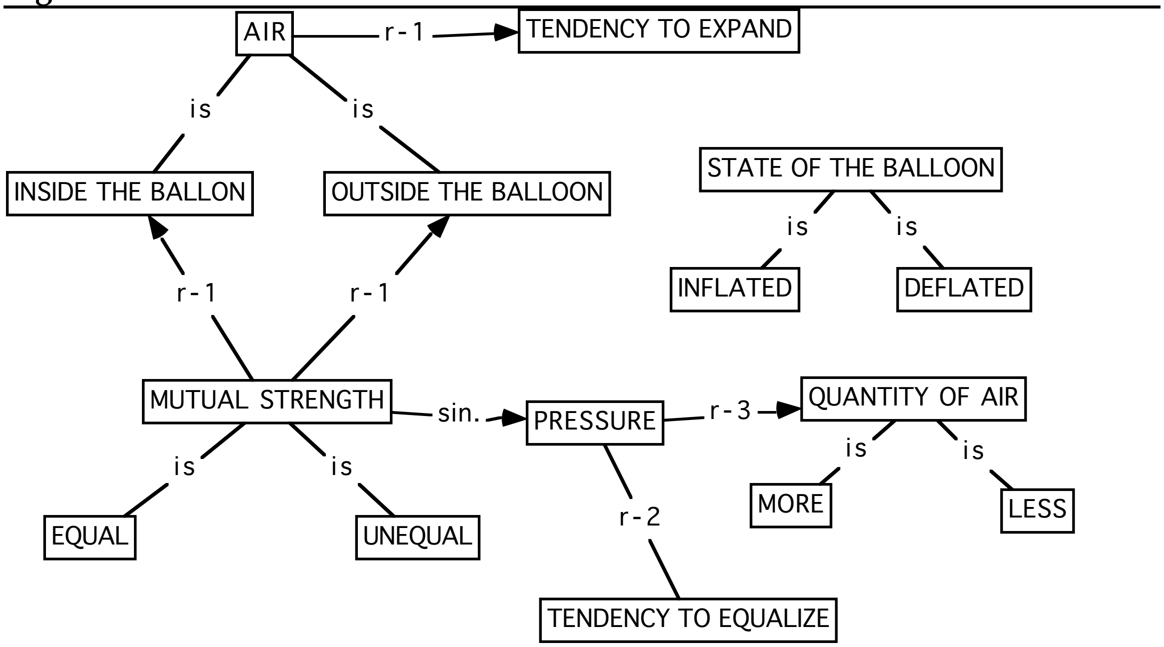
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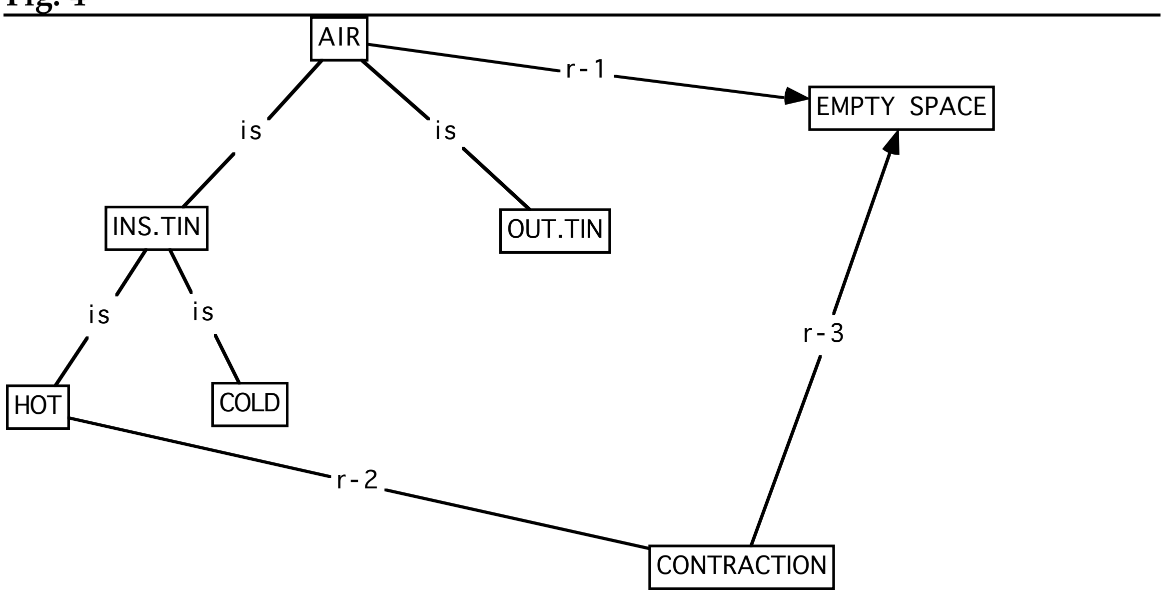
Fig. 4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r-2
CONTRACTION

Fig. 5

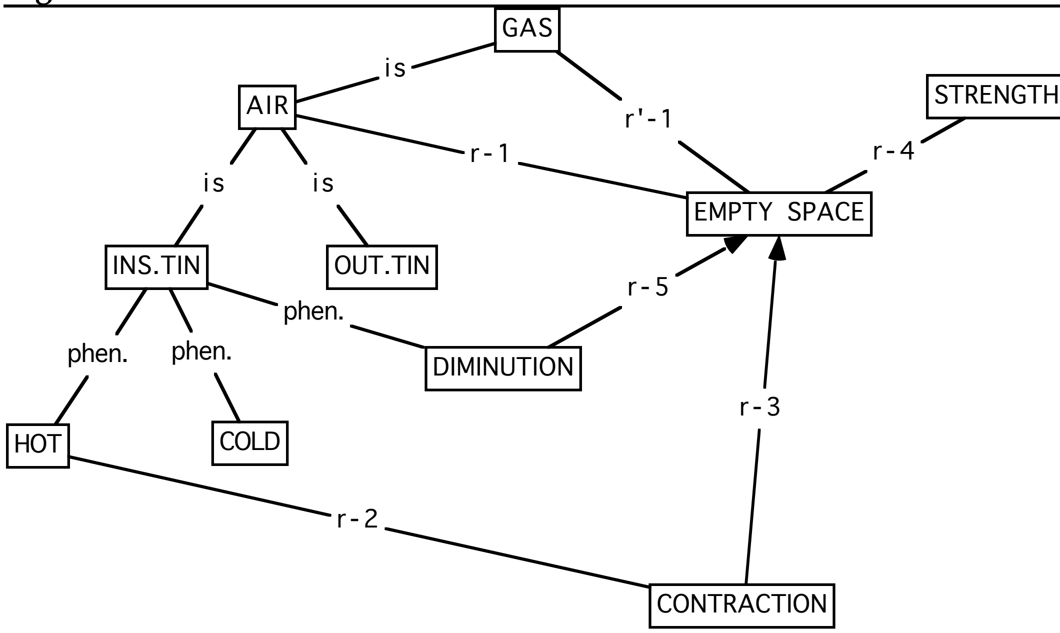


Fig. 6

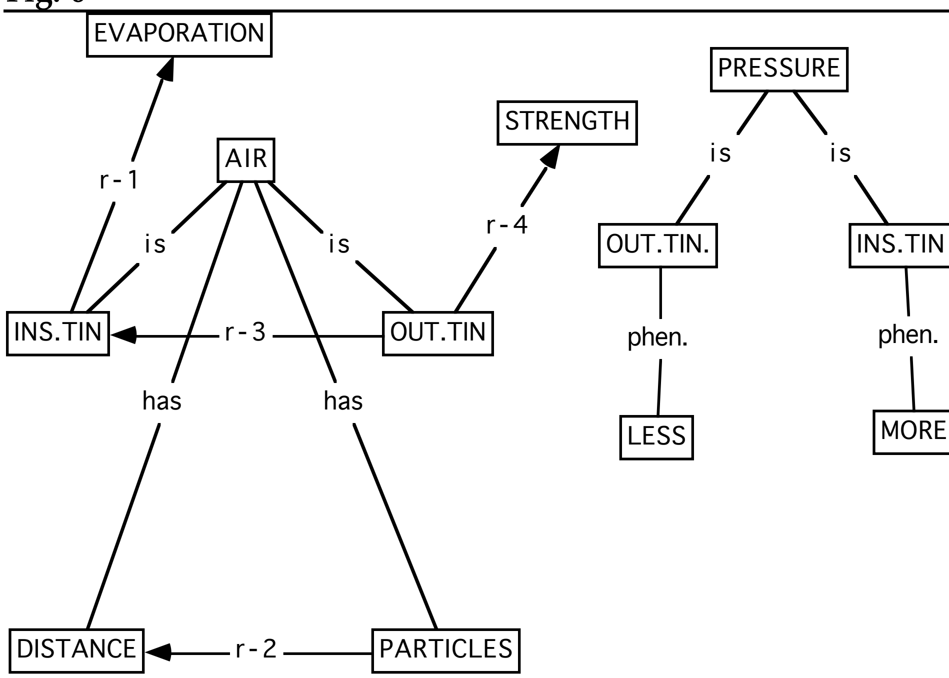
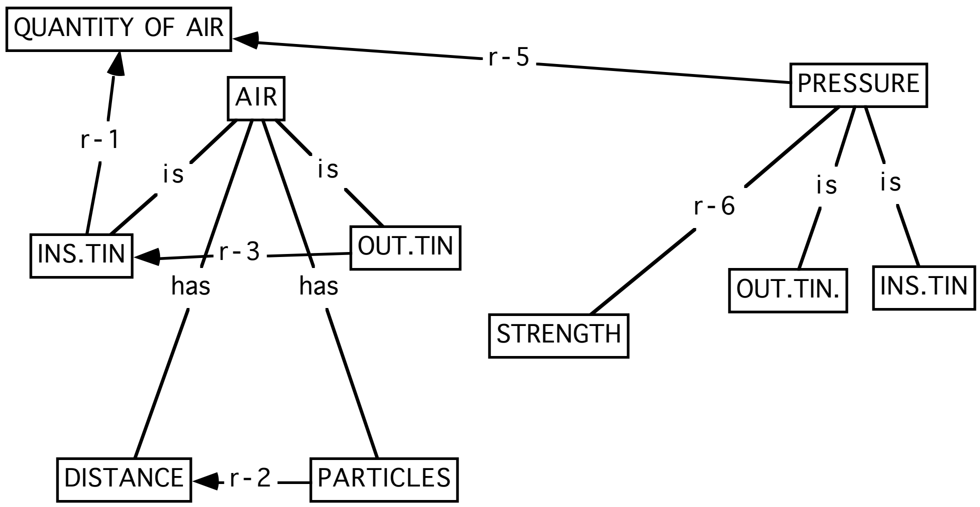


Fig. 7


QUANTITY OF AIR
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OUT.TIN.
INS.TIN
STRENGTH
DISTANCE
r-2
PARTICLES

FIG.6