Building bridges between common sense ideas and a physics description of phenomena to develop formal thinking

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1. Introduction: the main problems in physics Teaching/Learning (T/L)

A substantial scientific illiteracy amongst young people has been found (Euler, 2002; 2004) associated with a reduction of interest in physics (Cobal 2004). The way in which physics has been taught to date and the lack of attention given to didactic aspects and to learning problems have a relevant role in this crisis in motivation, although this is not the sole problem (Planinsic G, 2006). It has not been taken into account exactly what the student learns, despite numerous studies concerning conceptual knots (Duit R, 2006; Vosniadou, 2008). Physics has been taught in the same way in various types of schools and at all levels. Greater emphasis has been placed upon results rather than processes, using reductionism and schematizations, which destroy the capability to re-elaborate. Physics is therefore experienced as a difficult school subject which speaks of things that do not exist (the material point, the perfect gas,.), with difficult laws which one does not know when to use. The beauty, usefulness and the vast role of physics do not emerge through this type of teaching.
A demand for new educational modalities is emerging: this involves physics-related content such as cultural items, which the teacher proposes to students not to be reproduced, but to be used in a creative manner. It is necessary to create a knowledge of the subject which is not static and

definitive, but in progressive and continuous evolution, able to be utilized as a learning map to recognize and investigate problems, to resolve them in a creative manner without separating the product from the process, whilst enjoying a close relationship with the multiple dimensions of knowledge.

Physics education research investigates how to offer opportunities for understanding what science is, what it deals with and how it works, through direct personal experience with science itself.

We require working proposals to overcome the 2 main consequences of the methods followed to date a) initiate scientific education early, in kindergarten and primary school, as research shows that the child forms his/her first interpretative ideas at the same time as his/her first experiences with the phenomena occur, and research shows that this is both possible and highly important in learning development, b) proposal of physics T/L paths in vertical perspective with a wider cultural framework in relationship within the context, focusing on conceptual knots and thus overcoming the habit of producing the same basic module of a self-referenced nature, based upon the structure of the subject ??(thinking structure of the student).

Learning problems cannot be overcome through a transmission of knowledge from one person to another or (only) through games whose main purpose is for emotive reinforcement. Young people are prepared to be active in learning and playing games when they feel involved and are able to demonstrate their resources and skills in order that these may grow (Michelini 2006, Viennot 2007).

International research highlights the necessity of finding new educational strategies for the transition from common sense to a scientific vision of phenomena (Euler 2002, Cobal 2004, Planinsic 2006). It has been proven that personal involvement in the formulation of hypotheses, explanation of explored phenomena and evaluation of interpretative models serves to promote the learning process. Discussions and comparisons of ideas and cooperative work are efficient learning methods, facilitated by new technologies (Pfund 1995; Tornton 2009; Viennot 1996, Vosniadou 2008). Three main research problems arise in this context: 1) individualizing the common sense perspective with which different phenomena are viewed, in order to organize didactic approaches that take into consideration the viewpoint of the student, 2) the exploration of spontaneous reasoning and its evolution in relation to a series of problematic stimuli in specific situations, in order to formulate activity proposals, 3) recognizing the modalities for overcoming conceptual knots

in the learning environment in order to reproduce these conditions. A detailed revision of the topic content is at the root of the didactic project, based upon the results of this research.
The change in T/L processes produces a change in the role of the teacher, in his/her interaction with the class, in his/her capabilities (Wells, 1995). Teachers' professional development requires an integration of the subject, its methodological and didactic aspects (Pedagogical Content Knowledge), with classroom experimentation which is supported by exemplificative teaching materials (IJSE, 1994, Shulman 1995; McGilley 2006). For this reason empirical research into the learning processes and the development of formal thinking is linked through experience in action-research and contributes towards the development of material for class activities, which are able to establish the stimulus-question for reasoning in operative terms, and the conceptual course of the didactic proposal.
In this study we discuss the main problems in scientific culture and the role of teaching / learning physics, concerning the role of teaching strategies and methods for learning processes and Physics Education Research (PER). In particular we will present our research approach focalizing on innovation in T/L, the contribution of Information Communication Technologies (ICT) towards learning and the associated reasoning dynamics. The construction of formal thought is discussed in three fields: : 1) using the example of objectual models which favor the student's first interpretative steps, 2) illustrating approaches with ICT, 3) presenting a didactic path concerning quantum mechanics.

2. Common sense reasoning and interpretative models

In reading phenomenology there is a common sense reasoning which influences all of us. Its relative level of coherence contributes to its resistance (Michelini, 2001, Millar 2008, Viennot 2003). There are strategic angles where common knowledge interprets phenomenology. These strategic angles do not often coincide with the orthodox structure of the discipline. Scholastic knowledge and natural reasoning often co-exist within the same terrain (Viennot 2003). It is therefore necessary to find new approaches to physics, able to take into account the learner's perspective, the implicit natural reasoning with the correlated elements of coherence, to produce an evolution in the scientific way of thinking. Conceptual change (Vosniadou 2008) is a complex and long process concerning reasoning modality and methodological aspects, related to the subject topics.

This cannot occur without an individual study which indicates ways of considering the various aspects of the discipline.
Error is an indicator of conceptual knots: unclear elements of physics and phenomena interpretation in a contingent and local manner (Viennot, 1994; McDermott, 1993-2006; Michelini 2003).
The passage from local to global point of view is crucial to gain/attain? a scientific perspective: it is one of the main problems in our research.
Our research seeks to shed light upon ways of looking at phenomenology and upon common ways of reasoning and, in taking these into account, we aim to utilize these as an anchor for conceptual change in educational proposals. We are interested in the internal logic of reasoning and structure in terms of *Mental Models* (Gilbert, 1998) but, above all, their dynamic evolution following problematic stimulus (inquiry learning). Research-based experimentation allows us to explore the efficacy of the proposals of T/L in an operative way (Michelini 2003).
Rather than general results or catalogues of difficulties, we are interested in the obstacles that must be overcome to reach a scientific level of understanding and the construction of formal thinking. With regard to this aspect, the description of reasoning typologies is the main product of our research and forms the basis of the framework for the I/A proposals. Different departure situations produce different evolutions of reasoning and differentiated reference contexts for reasoning. In this way we identify useful paths for encouraging learning. Interpretative keys for entire phenomenological contexts emerge as we saw in the case of optic polarization for the analysis of quantum states (Cobal et al, 2004), with magnetic field lines for the study of magnetic phenomenology (Bradamante 2005), with the interpretation of thermic sensation for the study of thermic phenomena (Michelini et al 2004) and in the study falling bodies (Bradamante 2006).
The choice of reference situation, materials and modes with which to carry out the investigation of the dynamic evolution of ideas is never neutral. For this reason research in the phenomenological field is articulated along different lines and through different interventions in school classes, according with the Model of Educational Reconstruction MRE (Duit 2006), shown in Fig.1.
The main work in school classes is on the points A1.3, B and C for empirical exploration of spontaneous ideas and reasoning[1], for monitoring teaching/learning (T/L) proposals and for the analysis of the role of ICT and innovative strategies in overcoming conceptual knots. We carry out various interventions in similar classes, modifying support material and monitoring learning outcomes, according to data analysis of each intervention.

[1] The literature results in this field are at present mainly related to ideas as status level: there is a need for information on the dynamic evolution of reasoning in relation to educational strategies, methods, actions and contexts.

Fig. 1 – The MRE (Model of Educational Reconstruction) structure

A. Analysis of the structure of content

A1. Clarification of the subject:

A1.1 - text books and key publications

A1.2 - Historical development of ideas

A1.3 - Conceptions and Ideas of children prior to teaching

A2. Analysis of educative significance

B. Research on Teaching and Learning (T/L)

C. Development of materials and related research activities T/L with new methods.

The monitoring materials are stimuli cards, organized as inquiry learning tutorials (Mc Dermott, 1993), where for each situation and problem posed a Prevision, Exploration and Comparison question is asked (PEC strategy). For each answer an explanation and justification of responses given is required. We have found that the phenomenon of contamination of efficient reasoning is extraordinary during class discussions: we observe a radical change in point of view of an entire group of students with different ideas, through the effect of a single student who employs a reasoning process that is recognized as valid.
For a quality development of research in physics education it is necessary that the boundaries of the research carried out remain clear, in order to help us produce well-targeted proposals, that teachers may utilize as a reference, both to reflect upon concepts, and to re-elaborate activity paths in classrooms.

Mental, analogical and objectual models

A mental model is "A personal, private, representation of a target" (Gilbert 1998). Observing and examining a phenomenon implies an interpretation related to a way of thinking: a schema of reasoning according to an explicit or implicit mental model. The capacity to read, to influence, to control, to produce or to foresee a phenomenon derives from the construction of an (even partial) interpretative model of the phenomenon (Greca & Moreira, 2001). The interpretation produces important mental models which are analogical representations of reality (Johnson-Laird 1983) and conceptual frameworks (Euler 2001, 2004).
At a scientific level, making a bridge between local and/or? partial models based on contingent reasoning, and scientific interpretation, requires the overcoming of obstacles of a various nature, such as that of attributing a material nature to physics quantities. Our research found that objectual models were useful, in giving concrete representation to some aspects and behavior of

reality. They provide a concrete role for abstract ideas and may be used to test one's own ideas[2].
Let us mention several examples taken from our research at primary school level.

Mesoscopic model of ideal fluids in equilibrium.
In order to understand fluids it is essential to follow the conceptual path of an idea of a material point, which possesses its physical properties[3] as those of a continuous means, whose portions possess the properties of the entire system, distributed throughout the points of the very system. The mesoscopic model at the base of the theory of continuous means should be clearly explained, if one wishes to overcome certain learning difficulties of university or secondary students concerning fluids in equilibrium (Besson, Viennot 2002). We were able to concretize this for primary school children by identifying equal portions of volume (mesoscopic model of ideal fluids) with balls of rubber foam, in order to establish the idea of identifying equal portions of fluid with balloons filled with water. (Fig. 2a).

Figure 2 - Building the mesoscopic model of ideal fluids as an objectual (concrete) model made with rubber foam balls.

(a) The conceptual chain is: Water - Balloons of water as portion of fluids - Balls of rubber foam.	(b) The transparent box to see the balls' deformations.

This is useful to visualize the underlying idea and in order to reason about the concept of pressure, on the mechanisms that justify the pressure of the fluid in all directions (Pascal's law), and on the increase of pressure with depth (Stevino's law). If we fill a transparent vertical tube with balls of rubber foam (a single column of elements of volume) we visualize the increasing deformation towards the lower layers (Stevino's law): for each ball the deformation is the same at the same level and it is evident how this is independent from the number of balls next to it, which represent the entire volume. The concept of pressure as a distributed force is reinforced, and is completed by the idea of pressure as a property of the state of the elements of volume, which are also indicators of the variation of pressure. Pushing the balls of rubber foam with the piston in figure 2(b), we see: an equal deformation for each ball of the same row

[2] Just as Papert with his computerized tortoise from the Logo system provided a concrete context for developing geometry ideas, objectual models offer contexts in which one may develop and test ideas for physics models.
[3] The physics model of the material point for particle mechanics.

(horizontal), for each row of balls under pressure[4] and this pressure produces a further deformation in an orthogonal direction (vertical) for each ball, while also transmitting pressure towards the top and bottom due to the deformation that has occurred[5].

Figure 3 – The boat and the fishes

Figure 4 – Communicating bottle. There is the same pressure in the bottom ($P_A = P_B = P_C = P_D$).	Figure 5 – Hydraulic torch

The objectual model plays the role of a conceptual reference in order to interpret emblematic situations in the correct way, such as: a) the reduction in volume of an air bubble when it is compressed by water surrounding it. b) the pressure on fish as shown in Figure 3, c) the pressure at the bottom of connecting pools/vases (fig. 4) and d) the hydraulic torch (fig.5).

What does falling mean?

Letting a ball fall, why does it fall here? And at different points on the earth? The three categories of replies by primary school children are represented in fig. 6a-6b-6c: not all children are able to pass from a local to a global vision.(Bradamante 2006).

Fig. 6a: The falling is the same at all points: the ball falls on the ground, which is the earth, so the direction is different at the different points.	Fig. 6b: The falling is the same at all points around the Earth, but I have to represent the ground to show the vertical motion.	Fig. 6c: the falling is vertical at any point, such as here (only local vision)?

The objectual Eddington model.

[4] The model with the balls and the action of the piston constitutes the following first step in reasoning: the pushing action is distributed to all the balls from the surface of the piston which is exerting pressure and is transmitted to each horizontal line of balls behind those closest to the piston until the edge of the container.

[5] The second step of reasoning is the following: each ball is an element of volume which transmits to all the elements of contingent volume the variation of pressure to reach a state of equilibrium with the closest balls. When pressure is applied in one point a compression is produced on all balls in all directions. All of the balls in the container are compressed and reduce their volume in the same way.

To confront the problem of falling in global terms we built an objectual model, inspired by Eddington's idea (fig. 7). For the children it represents space in two separate and alternative ways: a) a small distance from Earth (free fall), b) the planetary level (interaction between masses).
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Figure 7 - A sheet of elasticized cloth attached to a square frame with a big ball in the center became Eddington's model for the study of falling bodies, varying the initial conditions. (Bradamante 2006)	

A sheet of elasticized cloth attached to a square frame, deformed by a heavy object placed in the middle of the cloth, became Eddington's model for the study of falling bodies with a variation in initial conditions (Bradamante 2004).The throwing of a small ball onto the cloth with varying initial velocities enabled us to visualize the global significance of an object falling in a certain place (local) and highlighted the existence of a situation where the ball entered a brief orbit around a central ball. When children consider ball motion on the region of space (field) represented by the model, they are able to pass from local to global vision.
Newton's mental problem of the throwing of a ball from a mountain with increasing tangential velocities was viewed with serious consideration by the children, who wondered where the ball would fall, when its velocity would carry it far from the Earth (Fig. 8). The children drew parabolic trajectories with increasing launching velocities, which curved more and more to return to the Earth. Four main trajectory hypotheses were produced to explain increasing velocities: parabolas which changed curvature and nevertheless reached a point on the earth, orbit, a flight with a straight trajectory, a local trajectory which fell towards the bottom of the page. Only 30% of the children were able to foresee an orbit, but their clear reasoning in the class group spread to and convinced the others.

The elevator model.
The discussion of the hypotheses in Figure 8 lead us to conclude that by falling one enters in orbit. Therefore to orbit signifies to fall. Astronauts are weightless. How do falling objects behave?
A transparent shirt box, inside of which we have placed various systems (a body hanging from a vertical spring, objects sitting on the base, a pendulum), became an elevator for the observation of the behavior of the systems during free fall and for reasoning on gravity (Bradamante 2006).
Our final test showed that 95% of children viewed "weightlessness" in terms of free fall both with the falling elevator and a spaceship in orbit around the Earth.

Figure 8 – The drawing of a nine year old child which shows the three categories of children's drawings from the same class, and in fact includes trajectories that have been created with local and global visions: the orbit has been cancelled! A borderline atmosphere is part of the mental model.	Figure 9 – The objectual model of an elevator made with a transparent shirt box, inside which we have placed various systems: a body hanging from a vertical spring, a pendulum,etc …. In free fall the bodies inside lose their weight.

The models of field

Eddington's cloth poses the problem of identifying the property of space represented by the cloth, which is produced by the presence of a weight, and which may have another weight fall upon it. The same problem exists for the space around a charged object. This becomes the site of a property, which manifests itself with the attraction or repulsion of a charge which it finds in this space. Also the space surrounding a magnet becomes the site of a property which orients the magnetic needles of a compass and/or iron-magnetic objects.

Figure 10. The magnetic field lines become concrete and play the role of an objectual model of magnetic field both when it is represented by the orientation of the needles of compasses around a magnet (10a), and when they are drawn (10b) (10c).

Figure 10a	Figure 10b	Figure 10c

How can I represent these different properties of space? How can I find a way to unite these, which also shows the differences between various examples?

Following Amperes' idea of field lines, we made an objectual field model using a group of specific explorers.

A polystyrene vertical platform with hinged straws weighted on one side, became a system of "gravity compasses" to explore the properties of space, to be compared with that of magnetic compasses (fig. 10) in the space surrounding a magnet (Bradamante 2005).

The equivalent circuit model

Various studies (Testa et al, 2006, 2008) highlight the widespread difficulty of students of different ages in understanding simple electrical circuits: the students do not apply functional reasoning. A system of small tiles with drawings of circuit elements became the environment for the modeling of simple electric circuits used to understand the modality for overcoming the topological knot in the functional behavior of circuits and for a reduction of complex passive circuits in terms of a simple circuit created by a power supply and a resistance (Testa 2006).

A computer tool to build a model of physics from reality

A Java applet on the web (Geiweb) was planned and utilized for the representation of aspects of phenomena in geometric forms, working on the representation of a real situation. The software acquired photographs of situations and used a design utility which allowed for elements of the model, such as straight lines-directions / rays of light, vectors / velocity / forces, to be represented in the same photo, or to be gradually removed in order to concentrate on the model, as in the case of Fig.11.

11a	11b	11c
Figure 11 - A situation of multiple optical images is conceptually reconstructed and transformed in a physics representation (11c), drawing the ray paths (11b) on photos acquired from the situation observed (11a)		

Contexts, strategies and methods to build scientific thinking

For scientific education it is fundamental to utilize the playing of games to explore different worlds and different ways of seeing these with hypotheses, which will in turn create other worlds or models in order to interpret these hypotheses.

It is therefore important to take advantage of game playing (see below) to provide contexts of learning constructions. One of the main challenges faced by informal education is how to cross social and cultural barriers between instruction and its utilization (Tuomi-Grohn e Engestrom 2003). This consists of a transition which involves (Beach 2004) the utilization of knowledge in different contexts and the assumption of responsibility and active roles.

Game playing

Game playing deserves to be addressed specifically. Games play an important role in the development of the subject (Vygotskij). Game time has a transitional nature between: the concreteness of action, and thought that is totally free of action, or rather, the capacity to abstract. The game context of playing ?(playing, not games)? offers an occasion for de-contextualizing with regard to scholastic activities, and the ?de-finalization? of games motivates and activates processes of personal learning and brings about a connection with a capacity evolved through game symbols. Through game-playing activities each experience is enriched by what has come previously and in some way will modify the games to follow (Dewey).

The rules of the game must be clear, and must relate to the emotional sphere; they must become an aim (work) and a learning experience (Vygotskij). The transition from action to abstraction is an internal process for those who are learning, which enables one to develop logical memory and abstract thought, finding release through the spontaneity of reality. Perception is the spring which pushes toward the acting out of this transition. By playing we increase the degree of awareness relative to one's own actions and the rules render the game even more enjoyable.

Game activities allow us to experiment with various frameworks and/or conditions / situations / ways of looking without conditioning and enable us to experience different styles and ways of thinking. In this way we construct worlds and different frameworks from which we begin to speak. The subject in this way amplifies his or her vision of the world and experiments ways of structuring thought with regard to the universe. It is fundamental in scientific education that games are used for exploring different worlds and different ways of viewing these with hypotheses, which create other worlds (models) to interpret these.

Playing at interpreting helps one understand how physics works. The strategy Prevision – Experiment – Comparison (PEC) is the path for learning to view processes in physics terms.
In order to create an environment of informal education capable of activating spontaneous explorations and building a bridge between common and scientific experience we produced the exhibition GEI (Bosio 1998) with 250 simple experiments to do and not only to see – they were hands-on and minds-on – in order to promote informal learning and free exploration of ideas and contexts in a qualitative and quantitative way. The simple apparatuses were created both for a basic exploration of phenomena and measures of quantities.
The research that has been taking place in Udine in this area since 1994 has been concerned with: a) exploration paths, b) conceptual laboratories, c) planning of experiments, c) learning processes and, in particular, the role of operativity in the personal construction of concepts, and interpretative models and representation familiar to students in the construction of formal thinking (Michelini, 2004).
Children spontaneously use symbols to represent abstract elements to which they give significance, as in the case of Figure 12 where we are told the story of two spheres of different material charged by rubbing on a chair, able to attract pieces of paper (Mossenta, 2006).

Figure 12 – Representation of two charged objects by children of six years of age.

The attraction between a steel sphere and a magnet (fig. 13a) or between two magnetic bars with opposite poles close to one another (fig. 13b) is represented in different ways, corresponding to the different meanings attributed to the process in both cases.

Figure 13 a – The attraction between a magnet and a steel ball is represented as a property of space.	Figure 13 b – The attraction between opposite magnetic poles is represented with arrows of action / movement or force.

Our research confirms that the operativity (practical and conceptual) [hands-on & minds-on] results in the subject's involvement with the interpretative problem, activating the resources and cognitive skills that help to separate the descriptive and interpretative spheres. The integration of classroom work with activities in other contexts, and with different groups of student, motivates exploration, stimulates the projectuality and activates the attention required for a comparison between hypotheses and data.

ICT to build the formal thinking

Physics is a formalized science and the contribution of the elaborator both in the collecting of experimental data and in the construction of computational models is part of the methodology of the discipline, with these hours dedicated to didactic activity. The contribution of ICT towards learning physics is extraordinary, however, on the methodological level. An example is provided by diffraction (Fig. 14).

A	B
Figure 14 – A simple hw-sw apparatus acquires the intensity position data of a diffraction pattern produced by a single slit (A). The data analysis offers the opportunity to relate numbers of order, position and intensity of maxima and minima to obtain the phenomenon laws. The computational model of Huygens sources (B) offered the opportunity to fit/assess? the experimental data	

It is also on the didactic level, as real time plots produce the imaginative transduction of phenomena in graphs: the typical language of physics (fig. 14).

Figure 14 – A small toy car is thrown onto the table, it goes straight then it stops. The real time graph of the position in time with respect to a sonar sensor helps one begin to read phenomena with graphic language.	

Through our research concerning the role and use of ICTs for learning we found that for formal thinking ICTs activate abilities relating to different kinds of sensorial information, experimental exploration, the building of formal thinking. ICT offers the opportunity to elevate the learning goals phenomena exploration with a sensor as an extension of our sense of the real world. Doing modeling for interpreting phenomena, in order to place the prevision, the planning of an experimental exploration, and the comparison between prevision and results into the hands of the students.

An approach to quantum physics to build theoretical thinking

In literature an increasing amount of attention is devoted to the introduction of quantum physics in secondary schools (Stefanel 2003). However, to date, there is no common point of view for an educational approach and the different possible formulations and interpretation of quantum mechanics (QM) have been used as a starting point for different didactic proposals: 1) rational reconstruction of the historical developments: crucial experiments and the birth of the theory of quanta, 2) wave formulation, 3) vector approach proposed by Dirac (Dirac, Sakuri, 1996). This approach points out the central role of the formalism in QM and how it is strictly interrelated with the conceptual aspects of the theory. It is a reference for our didactic proposals (Ghirardi, 1995; Michelini 2000, 2001, 2008) aiming to generate awareness of the fundamental ideas of the new mechanics and to offer the opportunity to build theoretical thinking (Ragazzon, 2004), having experienced the most simple iconographic representation adopted.

We decided to use polarization as a quantum property of light and to explore this as a phenomenon on experimental and analytical levels through simple experiments involving interactions of single photons with polaroids and birefringent materials (calcite crystals). The states of polarization of light are described in quantum terms by two-dimensional vector spaces (as it is possible for spin).

The main steps of the educational path are the following.

	To introduce the phenomenology of light polarization we use polaroids as explorers on an overhead projector. When light passes two polaroids with the permitted direction at 90°, the light intensity is reduced to almost zero. Therefore there is another property related to the intensity of light that I can produce with a polaroid and detect with another polaroid: polarization.

The measure can be carried out by means of a pen light and polaroids as follows.

The emerging light from the polaroid is always polarized along the permitted direction of the polaroid. This is the way/method? for the preparation of linear polarized light in a chosen direction.
Reducing the light intensity we find the same behavior. Therefore the results of the Malus law do not depend upon collective phenomena relative to the interaction between photons. The polarisation property is a property of the single photon due to its state.
The photons in the v state and property D pass the polaroid with the vertical permitted direction with certainty (all photons, each time) and are all absorbed by the polaroid with the horizontal permitted direction. In the u state and property * they pass the polaroid with horizontal permitted direction with certainty (all photons, each time) and are all absorbed by the polaroid with the vertical permitted direction. Therefore the properties D and * are *mutually exclusive*
If u and v are two vectors corresponding to two possible states of the system S, then even w=u+v is a possible state of the system S.
Let us consider some interpretative hypotheses for the ensemble of 45° polarized photons which are in the state (u+v) with associated property (romboid) ◊

	HP1: It could be thought as an ensemble of photons constituted by a statistical mixture of photons with properties * and D. If there were a statistical mixture of the photons with property * and D then a different result is obtained in comparison with the case of all the photons with the same property ◊. •

HP2: It could be thought as an ensemble of photons which simultaneously have two properties, with the same weight.
If the photons could have two properties at the same time and the polaroid has the role of selecting the known properties corresponding to its permitted direction. Not one selected photon will overcome the second polaroid with 45° permitted direction: this is in contradiction with the fact that half of the incoming photons pass the second polaroid and have 45° polarization.
We have to conclude that a photon with property ◊ cannot even have the property * or D. For that reason the property ◊ e * or◊ e D are called

incompatibles.This can be seen as a democracy of QM with respect to the photons: which wants to consider them all equals.
This illustrates the uncertainty principle which is an expression of the impossibility to observe two incompatible properties.
The question of the trajectory of photons can be analyzed as follows.

> The interaction with a polaroid produces the transition of a photon into a new state: no trajectory can be attributed, no locality and the measure of the corresponding property with the polaroid means to produce a precipitation of the system in those measured.

The case of two slit diffraction can be interpreted in this framework.

The conclusion of this discussion can be summarized as follows.

To formalize the concepts introduced we can consider N prepared photons (filtered by a F1 polaroid), whose? transition probability Pt is

$$\mathbf{Pt = Nt/N = \cos^2\theta}$$

Let us consider the transition probability Pt from state u to state w.

$$\mathbf{Pt = \cos^2\theta = (u \cdot w)^2}$$

Pt is the result of the scalar product between the two state vectors u and w of the photons passing the Polaroid F1 and F2 respectively

Concluding remarks: our research field in building formal thinking

The research carried out in Udine is located within the framework of empirical research designed to contribute to ??practice and in order to produce Teaching/Learning (T/L) proposals. These proposals, however, are not only limited to theories that function in practice. This task is often integrated with action-research in a collaborative dialectic between school and university. As well as contributions aimed towards didactic innovation with methodologies of research and development (R&D), we also study particular methodological aspects such as the role of ICTs in learning, processes of constructing formal thinking, the contribution of practical and laboratory activity in overcoming conceptual knots and the role of operativity and informal learning in order to identify approaches for conceptual change (Vosniadou, 2008). The first step in our research task is to rethink scientific content as a problematic issue, not only how it should be taught, but to rebuild this with an educative perspective.
In the last few years in particular, we have studied the building of formal thinking in border areas in the physics curriculum: the first step of scientific education (objectual models) and quantum mechanics for secondary school levels as a way to build theoretical thinking. The objectual models that we have presented in this paper are diverse by nature: objects that put into effect the properties of a system, such as the foam balls and Eddington's cloth, objects that represent systems equivalent to some of those of interest, such as the

elevator box; objects that represent systems of scale such as field lines and optic rays; analogical systems such as the example of electrical circuits. These provide a bridge for the construction of ideas and for physics models. Rather than being hindered by their partial nature, they must be rendered more concrete and explicit and stimulate discussion.
Certain software systems help us to construct the geometric models at the base of physics models through an approach that is phenomenological and possibly game-oriented, favoured by an informal context, such as the one provided at the GEI exhibition.
The ICT constitute a methodological resource for the study of physics, as well as facilitating its realization. Through experimental activity we realize the link between the concreteness of events involved in phenomena and their formal description via the data represented by graphs. This favours the interpretation of the comparison of results of computerized models with experimental data efficiently collected by means of computer on-line sensors.
In modern physics our approach to the construction of formal thought is connected to that of theoretic thought, through an approach to quantum mechanics as described by Dirac, based on experiments in optic polarization. It is the latter which is a property with two states, in which the vector spaces are reduced to real space and it is possible to confront this with rigour and thus formalize a new way of thinking as introduced by quantum mechanics.
At all levels we insist that one must not renounce the construction of formal thought, as it has been demonstrated that children attempt to attain this.

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Developing formal thinking and building conceptual knowledge as a background for formal interpretation of phenomena is one of the main challenges in teaching and learning physics. In the context of the experimental exploration of the electromagnetic phenomena, were investigated the pupilsâ€™ conceptual referents and representations of the phenomena and how they identify and explore conditions to ...Â A research focused on construction of formal thinking through CLOE allows to identify students' spontaneous ideas and conceptual paths into the evolution of reasoning in the interpretation of magnetic and electromagnetic phenomena. This particular activity was carried out with primary and lower secondary school students (from 6 to 13 years old; from 1 to 8 grade). Thus, the phonological description of language is effected by the science of phonology; the lexical description of language is effected by the science of lexicology; the grammatical description of language is effected by the science of grammar. The aim of theoretical grammar of language is to present a theoretical description of its grammatical system. To achieve this aim it is necessary to scientifically analyze and define its categories and study the mechanism of grammatical formation of utterances in the process of speech production.Â It presents a productive series of forms. A paradigmatic form â€“ a constituent of a paradigmâ€“ consists of a stem and a specific element (inflection, suffix, auxiliary word). The function of a grammatica paradigm is to express a categorical meaning. Building vertical paths in exploring magnetic phenomena developing formal thinking. Marisa Michelini, Lorenzo Santi, Alberto Stefanel and Stefano Vercellati University of Udine, Physics Education Research Unit, DCFA, Udine, Italy.Â We studied strategies to bridge common sense ideas with the scientific one in specific intervention modules.Â Data have shown that RQa1) an operative approach helps pupils to focus their attention on the physics relevant elements in phenomena; RQa2) the operative approach helps pupils bridge the space between a structural and a functional description of the apparatus; RQa3) comparison and analogies between artifacts elements and objects explored during the learning path allow pupils to re-use their.