LEARNING AND CONCEPTUAL UNDERSTANDING: BEYOND SIMPLISTIC IDEAS, WHAT HAVE WE LEARNED?

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INTRODUCTION

Science aims at providing synthetic descriptions of as many as possible aspects of the world, endowed with as great as possible explanatory and predictive power. To this end, entities, models and theories have been constructed and successively refined, constrained by the necessity of internal consistency and their confrontation with “the intransigent world of brute reality” (Ogborn, this book: B1).

It follows that learning science cannot be envisaged as a mere memorizing of “facts”. To benefit from the synthetic and parsimonious character of scientific explanations, that is to be able to analyse many particular facts at a time, there is a price to pay: understanding and handling non trivial relationships between different concepts, which are necessarily abstract. Conceptual understanding, which permits one to transfer an explanation of a phenomenon to different variants of a situation that have been previously analysed, is clearly a goal to be recruited under the label “learning science”, at any level.

Moreover, learning objectives about science should encapsulate ideas about the way scientists work, and how scientific knowledge proceeds, if the learner is to have an idea of what is science.

Centered on science learning, this chapter is organised around the following themes:

- Avoiding simplistic views: Here, through a brief reminder of some steps taken in science education research in the eighties-nineties, some basic models of learning and the rejection of some simplistic views will be presented.

- How and why introduce learners to the nature of science? The nature of science is clearly a desirable teaching goal, is it also a necessary pattern for learning?

- Some highly consensual positions about the teaching-learning processes. What should we retain as consensual – if not incontestable - concerning learning?

- The need to reconsider the content matter in detail, and to make precise decisions about what to spotlight in this content. This point, increasingly acknowledged as a decisive factor in learning, will be illustrated and discussed.

-Motivating students for science: is “science in context” the only way? The general concern about science students’ decreasing numbers as well as more precise considerations on learning processes might strongly orientate the choice of teaching strategies towards particular “contexts”. Can we enlarge the range of motive forces to be considered for learning?

AVOIDING SIMPLISTIC VIEWS ON LEARNING: WHAT WAS GAINED IN THE EIGHTIES AND NINETIES

Striking findings on learners' conceptions

Conceptual understanding, as opposed to rote learning or algorithmic execution of procedures, has been the target of a wide current of research for the last three decades. Knowing better the processes in play when learners' knowledge in science evolves, especially through teaching, became all the more crucial in the 70s as there was a notable disillusionment after a few big projects intended to improve science teaching such as PSSC in USA, Nuffield in UK, or PLON in the Netherlands, which turned out to be less successful than expected (Lijnse 1994: 94). The most important domain initially developed during the last three decades concerned students' pre-instructional ideas or beliefs that were not compatible with the science views. These "naïve ideas", "conceptions", or else "alternative frameworks" often turned out to be very resistant to teaching, which suggested that they are deeply rooted. The possibility that commonly used approaches to teaching were inappropriate also emerged.

For instance, as reported in the beginning of the eighties (e.g. Delacôte *et al.*, 1983, Driver *et al.* 1985), students in many countries were shown to give the same types of answers to paper and pencil questionnaires, associating motion and force in a quasi linear relationship, thus violating Newton's laws. Similarly, heat and temperature seemed to be confounded by many learners, if judged through their answers to specific questions. Or else, light was thought to be visible in itself, as a luminous source would be, whereas its path in empty space or in a medium can be detected only by its impacts on diffusive objects. In the same line, an optical image was commonly thought to travel in space as a whole, even said to arrive "erected this time" on a screen in case the lens in between the object and its image was removed.

After a few years dominated by the listing of these kinds of conceptions, the importance of highlighting more transversal aspects of reasoning - "mental models" (e.g. di Sessa, 1983) - or wider patterns of reasoning - appeared clearly. In particular, causality (Andersson 1986, Gutierrez & Ogborn 1992) and temporality were shown to provide good candidates to occupy a central place in the characterising of "common ways of reasoning". The "sequential reasoning" (Closset 1983, Shipstone 1985) about electric circuits consists in thinking of the current as starting from the battery, then endorsing different episodes (such as a using up of the current) with no reaction from downstream onto the upstream portion of the circuit. Far from a systemic view, the explanations in this domain were framed as stories. Rozier found the same flavour of chronology in explanations provided about multivariable problems, despite the absence of any circuit-like structure (Rozier & Viennot 1991, see also Viennot 1996-2001). In common responses to qualitative questions in thermodynamics, the different variables are dealt with individually and sequentially in a story-like series of cause-effect links, whereas, in the taught quasi-static approach, they should be seen as changing (quasi-) simultaneously under the permanent constraint of some simple relationships – such as $pV=nRT$. This kind of reasoning was shown to have an impressive generality, in physics and elsewhere.

An important point is that these fundamental ways of reasoning appear as even more resistant than particular conceptions considered in isolation. For instance at the end of their studies at university, most students correctly answer that two identical bulbs on each side of a resistor in a series circuit light equally brightly. But if they are destabilised by a less classical setting, like a black box between the same bulbs, they frequently give “sequential” answers, for instance: that the bulbs light equally brightly if there is no battery in the black box. As Closset highlighted (Closset & Viennot, 1984: 415), sequential reasoning adapts itself to new knowledge, but does not disappear in so-called “experts”.

After all of these findings, a view of the learner as a “tabula rasa” was unanimously rejected.

Another simplistic idea - that common trends of reasoning would be totally renounced by “experts” after a certain stage in the development of their knowledge – was less frequently argued against, although it deserves very serious attention.

Some distance was also taken (Viennot, 1991) from the idea that any “conception” would necessarily be *directly* inspired by everyday life: for instance, that in the absence of any lens, we do not observe on the walls an image “erected this time” of a nearby bulb, as would be suggested by very common students’ responses to classical tests. The hypothesis of a parallelism between the historical development of science and that of pupils’ ideas had also to be seriously reconsidered (Lythcott, J. 1983).

A natural outcome of these findings was to seek how to change current teaching practices, in order more efficiently to have students change their views. The question posed was how to optimise such a change, given particular teaching goals.

Among the various types of ‘outcomes for teaching’ that were suggested, at least can we say that *a consensus emerged (Novak 1988) to discard a purely transmissive model, according to which clear explanations of science phenomena and theories would be enough for students to learn them*. Such a model was no longer considered as a serious candidate to improve the common outcome of current science teaching with its cortege of unaffected misunderstandings.

However, as we shall see later, problems with a transmissive mode of teaching were often confounded with doubts about the authority of teachers and of scientific knowledge itself. ‘Avoiding authority’ became a main argument against transmissive methods, as opposed to their inefficiency.

“CONSTRUCTIVISM” RECRUITED FOR CONCEPTUAL CHANGE

These findings did not serve only to specify teaching goals – typically: changing students’ views concerning such and such common idea – but they were embedded in a widely shared “constructivist” perspective. As repeatedly claimed, children were not seen as passive learners, but were considered as “actively constructing their own knowledge” - innumerable references might be given here. Of course, some reductive comments may present this “constructivist” perspective as obvious, given that it is difficult to envisage a learning process in which the student would be totally passive. Such comments would result in emptying this idea of any noteworthy content. In fact, this current of thought strongly stresses as central for learning the student’s intellectual commitment to confront his/her previous knowledge, the kind of experimental evidence available to him/her and others’ ideas. As Duit & Treagust comment (2003: 673) quoting Duit (1999), “conceptual change has become the term denoting learning science from constructivist perspectives”, given that usually students’ conceptions are in stark contrast to the concepts to be taught or to the views of science to be developed.

What might be called “the conceptual change movement” was clearly rejecting a purely transmissive model, but also discarded was a model of purely inductive rediscovery, relying only on the autonomous confrontation of the learner with experiments. Be it only by selecting learning tasks, or more generally by designing detailed guiding strategies, researchers widely proposed and experimented with ways of teaching in which the teacher takes an important place.

The need to reject the simplistic model of purely inductive discovery learning is clearly agreed on in the science education research community.

This said, students' conceptions may be seen as impediments to be fought, in line with Bachelard's claim (1938: 14) "on connait contre une connaissance antérieure, en détruisant des connaissances mal faites (…)", or as a starting points on which to build – or "to scaffold" (e.g. Scott *et al.*'s, 1998) - new knowledge, through a step-by-step process, carefully guided.

Cognitive conflicts – supposed to occur when an experiment contradicts a learner's expectation, or when incompatible ideas are in competition -. thus came to be seen as central to learning, and - very often - as a necessary starting point of teaching.

A particularly well-known conceptual change model was that proposed by Posner *et al.* (1982) and subsequently refined (see for instance Hewson & Hewson 1984, 1992). In this model, a radical conceptual change – as opposed to a mere adaptation - is envisaged. Such a change is supposed to occur when a student is dissatisfied with an initial view, provided a new conception appears as a good candidate for replacing the prior one. The conditions to be fulfilled by the replacement conception are that it is intelligible, plausible and fruitful. This means that its meaning is understood by the learner, who finds this new idea believable, and that this idea brings with it some benefits: solutions to various problems or stimulating questions. Beyond the idea of a cognitive conflict raised by the unexpected result of an experiment, that of competition between several conceptions available to the learner is central in this model. However it must be kept in mind that the conditions required for a replacement conception were to be seen as necessary, rather than sufficient.

Some difficulties were encountered in trying to find clear evidence of what might be called a better "efficacy" of strategies based on cognitive conflict and on the conceptual change model just described. In particular, it was often observed that a cognitive conflict intended by the teacher was not recognized as such by the students.

This is an important point to consider: again, it would be simplistic to think that a counter intuitive experiment will necessarily produce a clearly acknowledged conflict.

Moreover, investigations based on a conceptual change model by no means led to claims that students had replaced once and for all an initial view by another one.

Thus, a simplistic interpretation of a conceptual change model as involving a simple one-for-one replacement could not be sustained.

In contrast to a view of learning based on conflicts, some authors made the point that students' prior ideas should be taken into account in less confrontational a style. For instance, Clement (1987, see also Clement & Brown 1989) proposed a teaching strategy based upon the development of ideas consistent with the views targeted by teaching. Others (Niedderer 1987, Solomon 1983) suggested that it was possible to develop a scientific understanding in parallel with existing notions, with the view that students be taught how to recognize which model was applicable and appropriate in which situation. To learn scientific concepts would then mean learning the differences between everyday-life thinking and scientific thinking.

Some strong critiques were expressed (e.g. Solomon 1991) of a teaching strategy involving sorting out of ideas expressed by the learners into acceptable ones and others to be rejected. Stavy (1991) argues that emphasizing conflicts may result in students' loss of self confidence, with negative learning effects. Also, Lijnse (1994) has pointed to the apparent contradiction between suggesting that learners should actively construct their own knowledge while starting with a frontal devaluation of their initial views, through cognitive conflict. He suggested that, rather, students' own questions and personal interests should guide the design of activities in class, with a major concern for seeking answers to problems explicitly posed by them. In the same line, Gil Pérez *et al.* (1999; see also Gil Pérez, 2003) underlined that fighting wrong ideas did not constitute *per se* a valuable motivation for the learner, and stressed, quoting Bachelard (1938), that the development of knowledge was in fact activated by the need to answer a question or to solve a problem.

In considering such positions, at least two aspects need to be taken into consideration, in various proportions - in as much as they can be separated. One is the consideration of what science is and the other is students' motivation. These aspects are discussed below.

THE NATURE OF SCIENCE, PATTERN FOR LEARNING MODELS?

A question arises: it is agreed on that the nature of science is more than a recommended teaching goal, but is it also a necessary guide to shape the design of teaching strategies? This question can be posed concerning all the variants of conceptual change models outlined above.

Near the end of the 1980s, Millar (1989) posed the question: should a model of teaching necessarily be determined by a model of learning, itself reproducing a model of genetic development of knowledge – e.g. that of Piaget? His own answer was negative.

More recently, Ogborn (1997), drawing in particular on Suchting (1992) and Matthews (1994), mounted a frontal attack against the epistemological foundation of constructivism – be it called "educational" or not as it appears in many of the initial defenders of this current of thought (Novak 1977; Driver & Oldham 1986; Millar & Driver 1987; von Glasersfeld 1987, 1989; Driver 1989). Why, he argued, should science be learned the same way as it was built?

With this criticism, Ogborn targets a particular view of scientific knowledge: that it could only be "made", with open choices, in contrast to "finding" some aspects of brute reality, severely constrained by some built-in laws. This author pinpoints for criticism an idea that emerges from the constructivist writing, namely that our lack of direct access to reality implies that no construct is more valid than another one. Similarly, he argues that a constructivist position denying that telling could have any role in teaching reduces itself to absurdity.

This direct attack may seem surprising given that, taken separately, *some* of the quotations targeted by the author's critique may seem innocuous, at first sight: "…such constructivist approaches view knowledge as personally and socially constructed, rather than 'objective' and revealed; theories as provisional, not absolute. (Millar & Driver, 1987: 57)". The same might be said of Driver and Easley's statement (1978:76, quoted by Taber, 2006: 146), presenting "knowledge about the physical world" as "agreed conventions concerning useful ways of analyzing and interpreting events". However, an accumulation of such writings, when not accompanied by clear statements acknowledging that not everything can be successfully “made” or “agreed on” in science, certainly deserves attention. Thus, a statement such as “ (…) a central feature from the students’ point of view is that knowledge is not provided for them ready made” (Scott *et al*., 1998), might be seen more profitably as an incitement to maximize student’s intellectual activity than as an absolute directive, excluding any ‘telling” component.

This said, regardless of a particular view of science, the question posed remains: whatever the view of science targeted by teaching, should learning mirror the processes by which knowledge in science is supposed to be constructed? As seen above, Ogborn’s response was clearly negative. In more defensive a style, Taber (2006: 171), explicitly states in a review paper entitled ‘Beyond constructivism (…)’: “ Yet in the model presented here, the hard core (…) posits an assumption about how learners come to ideas about the world, but does not imply assumptions about the nature of knowledge and reality.” At least can we say that, if a strong flavor of relativism had seemed orthodox at one time, there are now some authors who clearly want to spare constructivism of this theoretical load.

It is certainly of great value to put learners in a situation of personal – or better: collective – investigation, for many reasons including the existence of *some* similarities with what a scientist does. This does not mean that nothing else has the least value.

In any case, a cautious position in this respect is clearly advisable. Indeed, the best attempts at putting learners in a situation of a research-type might be criticized as offering a distorted view on what scientific activity is (see for instance Gil-Perez *et al.,* 1999: 507). Moreover, being conscious of not being able to represent adequately how science proceeds does not prevent one from designing learning situations which present highly beneficial similarities with research situations.

CONSENSUAL POINTS

It is striking that, across all these analyses and criticisms, some strong points emerge, beyond the common rejection of a purely transmissive or a purely inductive model.

Thus, Scott *et al.* (1998) associate “conceptual change teaching” with the following demands on teachers

“The teacher is required to:

- be aware of students' ideas and understandings relating to the topic under consideration.
- be aware of likely conceptual pathways for that topic;
- be sensitive to students' progress in learning;
- be able to generate learning tasks to support and encourage that progress in learning;
- be sufficiently confident in his/her own understanding of the subject topic to be able to appreciate, and respond to, differing points of view;
- be able to organise and manage a classroom which will allow for all of this to happen.

Ogborn (1997) does not contradict these claims when he holds strongly to the following "four essential points" attached to educational constructivism:

- the importance of the pupil's active involvement in thinking if anything like understanding is to be reached;
- the importance of respect for the child and for the child's own ideas;
- that science consists of ideas created by human beings;
- that the design of teaching should give high priority to making sense to pupils, capitalising and using what they know and addressing difficulties that may arise from how they imagine things to be.

Especially stressed since the nineties is a concern originating both in a "social constructivism" backed up by Vygotsky's writing (1969/1934, 1978) and in a view of learning as driven by a need-to-know, and relevant-problem-solving activities. "Science-in-context" is a label often used to refer to this compound of aspects: Duit & von Rhöneck (1998) express this view: "Conceptual change, therefore, has to be embedded into conditions that support the development of students' ideas. Among these supporting conditions are a classroom climate that allows students to voice their ideas and to exchange their views with other students, and where students' ideas generally are taken as serious attempts to make sense of a certain phenomenon by the teacher. Also students' interests and motivation play a key role." As Duit & Treagust (2003: 680) reaffirm: "Clearly, it is an important aim of science education to develop interest in much the same way as to develop students' pre-instructional conceptions towards the intended science concepts".

These points are presently quite consensual among researchers in science education. This does not mean that these are empty statements, just low options in a soft consensus, which would not determine anything particular. Putting them into practice is a real challenge. These statements avoid caricatured interpretations that appeared, at their time, as a kind of constructivist orthodoxy. These "essential points" leave room for, indeed call for, considerable and patient work in order to design science teaching accordingly. They have inspired many recent efforts towards more completely specified theoretical platforms and practical suggestions. Thus, Andersson and Wallin (2006), referring to Ogborn's suggestions (1997), recapitulate what they consider as appropriate to promote learning with understanding:

1 The teacher looks upon himself-herself as an active representative of the scientific culture, who introduces concepts, gives scientific explanations, and arranges situations for applications of these concepts and so on. (…)

2 The teacher is well acquainted with common alternative ideas of the teaching content and is aware of these during teaching. He/she is attentive to and interested in the pupils ideas, both those already known and the new ones.

3 the teacher creates a permissive classroom climate in which the pupils can share and discuss their ideas and reflections in a positive way. (…)

4 A fair amount of time is used for discussing and solving problems/ problems involving the pupils in having to apply the teaching content in different situations.

5 Deep learning is encouraged; that is, the pupil is stimulated to

- "twist and turn" the new knowledge in his/her head (transformation instead of memorization),

-ask questions and suggest ideas,

-connect new knowledge with existing knowledge,

-use knowledge as a tool for seeing the world around him/her with new eyes,

-discuss what is new with classmates and others, and

-accept challenges (e.g. in the form of set problems).

6 Formative evaluation is used in various ways by both teachers and pupils with the purpose of improving teaching and learning.

7 The teacher does not assume that the student is motivated, but acts to create interest and motivation.

But as Andersson and Wallin stress (2006: 676), in line with Lijnse's previous claims (1994, 2000), general recommendations are insufficient when it comes to designing teaching of a particular content. There is a need for content oriented theories as exemplified in a recent international course significantly entitled "Rethinking Science for Teaching, some research problems" (Guidoni, 2004). Recalling the main characteristics of their model of "educational reconstruction" (Kattmann, U. *et al.*, 1995), Komorek and Duit (2004: 623) speak of a "content structure for science instruction" that "has to be constructed on the grounds of an analysis of the educational significance of the content and on the basis of students' learning difficulties". With an increased stress on motivational factors, these authors voice the same need to reconsider and reconstruct a content for science instruction "that is not simply a somewhat simplified version of the content structure of science." (see also Méheut & Psillos 2004).

In the following, these two points – "rethinking science for teaching" and motivational aspects are examined in more detail.

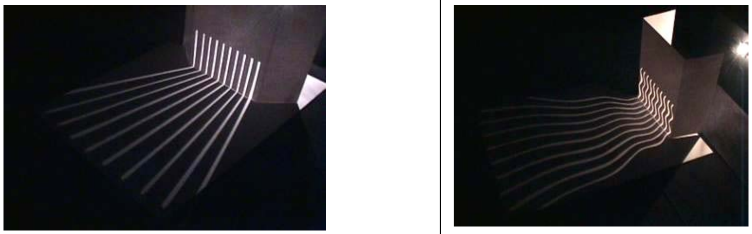
SPOTLIGHTING A CONTENT FOR TEACHING: "WHAT-AND-HOW"

It has been argued that it is essential to take learners' conception into account, be it as stimulating obstacles or as a starting point for gradual change, with a view of bridging common knowledge to the desired views. It is also a widely shared viewpoint that learners should not be left on their own to negotiate with their previous thinking, if conceptual change is to be reasonably expected. Guidance is widely called for (e.g. Scott *et al.* 1998, Gil *et al.*, 1999*)*. What guidelines can we find in this respect? Millar (1989) insisted that the guidance should be decided at the microlevel, as did Lijnse (1994, 1995) starting from other premises.

Speaking of guidance means to know what it is that the learner should understand. In particular, the fact that some conceptions are declared "alternative", or, in a more brutal way, "erroneous", does not designate unambiguously a desirable target of teaching. As soon as the early nineties, attention was called to the importance of a thorough reconsideration of the science content (Fensham *et al.,* 1994, Tarsitani & Bernardini, 1995). It has been stressed that the knowledge to be taught should be 'manipulated' for teaching (Tiberghien, 2000: 28, referring to Chevallard, 1985), or 'staged' (Leach and Scott, 2002: 115). This does not mean that the starting point of such a transformation is a unique, unproblematic "science content" or "scientific knowledge" from which a part would have been chosen, *then* transformed. Even excluding any relativism, and acknowledging the existence of constraining physical laws built in reality, a *choice* is to be made *from the start* as to what to “spotlight” (Viennot, 2002: 12 and 2003: 2) in the science content.

There is a strong mutual relationship between the ‘staging’ of a science content for teaching and the chosen spotlighting of this content, in other words the aspects of this content that have been *chosen* as central in the aimed-for comprehension. The “what” and the “how” of teaching overlap. Their links should be examined in the light of learners’ common conceptions and ways of reasoning, as well as of a thorough content analysis; this without losing sight of the distance existing between the learner’s conceptual starting point and the targeted understanding - the ‘learning demand’, in Leach *et al.*’s terms (2002). Examples are now numerous. Thus several authors (Härtel 1985, 1993, Sherwood & Chabay 1993, Psillos 1995,) chose to underline the transient phases of a series circuit. The rationale was first to provide students with a causal view of electric circuits, in order the have them subsequently accept the systemic analysis, with conservation of current around the circuit. This means taking students’ intellectual preferences and needs into consideration, by allowing them to imagine what happens to electrons just after the circuit is closed, until the flow of charge is the same along the whole circuit. Doing so, the difference between a propagative transient - during which the current is not the same everywhere in the circuit , and a quasi-static transient – like that classically considered for the charge of a capacitor has to emerge. Regardless of the model they proposed to analyse the transients, this focus constitutes a very specific spotlighting of the “science content”. More recently, Colin (Colin & Viennot 2000, 2001) suggested stressing, in wave optics, the “backward selection” of relevant paths of light by the arrival point, i.e. a point on a screen or a sensitive surface of a receptor. This suggestion is twofold. It responds to several learners’ common trends: to be over-influenced by surface features of diagrams – any set of parallel lines would represent a plane wave , and to see a ray as a ‘hero’ of a story (told forwards), with a unique fate, identified and individualized up to the end. It also underlines some deep and unifying aspects of the domain, ultimately referring to quantum mechanics. Another example is the choice of a mesoscopic model to teach hydrostatics or friction (Besson & Viennot 2004) which relies, in the authors’ rationale, on a concern to address some students’ conceptions and difficulties, but that also strongly orientates the taught content towards views that are very relevant in contemporary physics research.

In line with this thorough attention to the content matter, some strategies that may seem at first sight to be “mere details” have been pinpointed. For instance the use of “materialized” rays in optics to introduce rectilinear propagation has been much criticized. The critique is not that it is an inefficient teaching technique, but that it gives a distorted idea of what the *model* of a ray of light is, while reinforcing the common idea that light is visible from the side. Moreover, when it is associated with the use of a “ray box”, this strategy gives a poor impression of the consistency of physics. In this case, a luminous track with rectilinear limits, a shadow, is seen on a horizontal surface, coming from what seems to be its source. But the only light source is a lamp situated behind the slits, two centimeters *above* the surface. Such critical details of teaching practice (Viennot *et al.* 2004) are, so to speak, very well localized points of articulation between the “what” and the “how” of the teaching-learning process. The use of images in teaching (Pinto, 2002), the strategies of laboratory work (Séré, 2002; Leach & Paulsen, 1999), or else the use of microcomputers (Stylianidou *et al.*, 2000, 2005; Sassi *et al.*, 2004; see also Thornton, this book, section E2) raise the same type of concern, and have been considered at the same fine grained level of analysis.



a) A common experiment often presented as “showing” rectilinear propagation of rays of light

b) A way to show that the straight lines seen in a) are not so simply linked to rectilinear propagation of light

Fig. 1. a): An example of a “critical detail” of ritual practice. b): A way to introduce an appropriate analysis of the phenomenon (in fact: shadows). In b) as compared to a), the “how” of teaching reshapes the “what” of the targeted learning. (photos: Wanda Kaminski, personal communication)

ENGAGEMENT IN LEARNING ACTIVITIES, INTELLECTUAL EXIGENCY AND LEARNING

The fact that content analysis, attention to students’ ideas and the consideration of critical details determine different spotlighting of the taught topic, as illustrated in the examples just quoted, goes with a certain level of exigency concerning the consistency of physics. If a rectilinear shadow is mistaken for direct sight of rectilinearly propagating rays of light, it can seem to belong to a very superficial approach. It is certainly more demanding to consider that there is no source for such a “ray”. Moreover, the person who can go beyond a superficial view and gain access to a simple but non obvious analysis, like that considering ray boxes in terms of shadows, may feel happy for this.

On the other hand, it may be argued that the need for an exigent analysis constitutes a potential barrier, the contrary of an attractive factor. This discussion leads one to consider a theme widely advocated in recent models of learning: the supposed importance of “context” for motivation .

As recalled before, it is often advocated that knowledge develops in answer to a problem and that learning should proceed along the same path. Accordingly, the “problems” thus taken as the motive force for learning should be relevant for the learners, that is connected to everyday life, social or environmental questions; all this being not exclusive of some questions which benefit from their spectacular connotation and which raise dreams, as for example astrophysics. The benefits to be expected from such an approach, in terms of students’ motivation, seem unquestionable. Purely academic courses, devoid of any connection with aspects of the world relevant to youngsters, would clearly be negative in terms of science attractiveness. But some questions remain.

- In order to facilitate conceptual learning, should we rely *only* on activities framed as guided problem-solving?

- In order to engage learners in learning activities and to be attractive, is it so clear that science teaching should *only* deal with the kind of topics - relevant or exciting - that are commonly advocated? Or can we *also* raise intellectual satisfaction on the basis of the elegance and consistency of physics theories *per se*?

The first of these questions, in the present state of research, would get a negative answer. Sustaining a positive answer, that is taking an extreme position, would lead one to the kind of contortions needed to present *any* entry into a topic as "problematised", and, given the risk of increased temptation to extreme empiricism, *any* piece of knowledge as the result of personal inquiry. Of course, it is possible to present a classical episode of teaching as a preparation phase, for an ulterior problem solving activity. But it might be more useful simply to accept that 'telling' is a legitimate and necessary component of teaching, given that "to teach is to act on other minds which act in response" (Ogborn *et al.* 1996: 141). Trying to make sense of what is said or shown by someone else is a way to learn, even if there are other conditions to be fulfilled simultaneously in order to optimize "(…) a 'widely resonant understanding and learning re-actions" (Guidoni, 2004: 224).

Among the facilitating factors is the possibility of discussing with peers and/or with a teacher acting as mediator, thus making explicit and discussing views in competition. This point is very often advocated, since Vygotsky's work (1969/1934, 1978) turned out to have a great impact (e.g.: Lemke 1990, van der Veer & Valsiner 1991, Leach and Scott 2002). In a special issue on the theme of "context-based chemistry education", Gilbert (2006: 965) recalls that a stress on context-based education does not offer *per se* a simple and miraculous access to conceptual learning, and lists the criteria that he considers appropriate to define a "context" favorable to this end:

> (i) Students must value the setting as a social, spatial and temporal framework for a community of practice. They must value their participation in a community of practice through productive interaction and develop personal identities from the perspective of that community. (…). These settings must clearly arise from everyday lives of the students (…) or social issue and industrial situations that are both of contemporary importance to society.
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> (ii) In order to be of high quality, the learning task must clearly bring a specifically designed behavioural environment into focus, since the way the talk is being addressed, the type of activity engaged in, is used to frame the talk that then takes place (Greeno, 1998; Vygotsky, 1978). The task form (Finkelstein, 2005) must include problems that are clear exemplifications of chemically important concepts.°
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> (iii) Learners should be enabled to develop a coherent use of specific chemical language. Through the talk associated with the focal event that takes place, students should reach an understanding of the concepts involved. They should also come to knowledge, in accordance with the general ideas of constructivism, that such specific language is a creation of human activity. With respect to idioculture (Finkelstein, 2005), the teacher must know the background knowledge of the students.
>
> (iv) Learners need to relate any focal event to relevant extra-situational, background knowledge, building productively on prior knowledge that is, partially at least, composed of the learner's own ideas. They must be able to "resituate" (Greeno, 1998) or "recontextualise" (Van Oers 1998) specific language in order to address the focal event at hand. A vital source of focal events will be those with major public policy implications (e.g. global warming; stem-cell biology).

It is noteworthy that these criteria encapsulate some general aspects of constructivism consensually valued as favorable for efficient learning and listed above. Added to these essential points of constructivism are some features originating in a socio-cultural approach and more specifically referred to the idea of "context", be it only the notion of "focal event" preferably endowed "with major public policy implications". From this standpoint, some recent results about boys and girls respective interests (Häussler *et al.*,1998; Stark & Gray, 1999; Lavonen *et al.*, 2005; Schreiner & Sjøberg, 2005; Trumper, 2006) provide guidelines well worth considering (see also section D3 in this book). This said, the list of criteria proposed by Gilbert may give the impression that we, as teachers, are facing an almost impossible task: There is an obvious need to adapt these thoughts to practice, and to take these as a source of inspiration without getting paralysed by such a "teaching demand", to paraphrase Leach and Scott (2002).

As for the second question - concerning the part of intellectual satisfaction *per se* in students' pleasure to learn - there are presently very few, if any, investigations directly targeting this question. Most of the time, what is evaluated concerning learners is their conceptual achievement. Global appreciations of such and such type of topic (see above) or of a particular curriculum (for instance Hunt & Millar, 2000) have also been reported. But the level of intellectual satisfaction reached after a *precise* teaching sequence seems not to be, *per se*, a commonly valued research target. It might be argued that an exigency of consistency was long supposed to underpin cognitive conflicts in learners, with more or less dramatic "accommodation" phases, to borrow Piaget's terminology. But this was seen as a phenomenon, and referred to "cold cognition" (Duit & Treagust, 2003: 679, quoting Pintricht *et al.*, 1993: 168). Rather, it might be seen as a lever to be deliberately used in order to raise students' *(hot) intellectual satisfaction, via a stress on consistency, elegance and parsimony of the taught theories.* In an investigation conducted following this last perspective, it appeared that the common teacher pessimism concerning their students' wishes on this ground was not supported by other results concerning novice learners (Viennot, 2006). Some students, in particular some beginners at university, were confronted with a relatively exigent approach aimed at criticizing a statement and linking two different solutions for a classical problem, concerning a topic with low, quite anecdotal, relevance – a hot air balloon. Their extremely positive reaction – "thank you, you have made me think", which did not exclude realism: "*(this approach is more interesting)* absolutely, provided we are taught how to do it" – is in stark contrast to some teachers' comments, that might be summed up as "*(this analysis)* it's good for us, for not for them". The questions raised by such (limited) results deserve, I suggest, further research and reflection.

CONCLUDING REMARKS

Throughout this period of about thirty recent years, the numerous attempts at representing learning processes in science have raised rather consensual viewpoints, beyond serious confrontations. It is by losing their radical character or by broadening their narrow vision - as recommended for instance by Duit and Treagust (2003; see also Tyson *et al.* 1997) - that the diverse theories have contributed to such a consensus. Thus, it seems useful to hold to an approach to learning which excludes a purely transmissive model without excluding the central role of the teacher, which considers the virtues of experiments without falling into a new empiricism, which excludes a dogmatic view of science without imposing a dogmatic relativistic epistemology, which puts learners "in context" without getting paralysed by an absolute and permanent need to simulate social activities. A master word for the practitioner might well be a search for an appropriate *balance* between the different ways to comply with the essential points of constructivism listed previously, the criteria defining a context favorable to conceptual learning and the material and institutional constraints of teaching.

In this search for an appropriate balance, it might be considered realistic to envisage on the one hand a limited number of very consensual and basic principles – like Ogborn's four essential points –, and on the other hand a thorough and fine-grained attention to content specific aspects. The notion of content-specific theory – based on a combined consideration of a content analysis and of students' ideas – has gained ground since the first suggestion of this type made in the mid-eighties by Hartël. In between these two levels of reflection, one very general and the other very specific, as much consistency as possible should be aimed at. It is less generally agreed – or at least less uniformly stressed – that every other condition imposed by various authors on the context of the teaching-learning process must be fulfilled to reach appropriate conceptual understanding. For instance, it might be seriously envisaged, to say the least, that intellectual satisfaction and deep understanding can be reached through work on very ordinary topics – i.e. topics that are not especially relevant or socially significant.

What has been gained during these years, despite our uncertainties, is of great value. Simplistic and narrow-minded ideas left aside, a panel of content-specific suggestions for teaching, in line with agreed upon basic ideas about learning, have been constructed and validated. Even if a "grand unification" theory of learning is not yet available, some critical differences in learning outcomes have been targeted, observed and interpreted.

For a practitioner who desires to better understand how learning occurs in students, patient and devoted work on the basis of this existing collection of suggestions is certainly a valuable entry, even if research, of course, has to proceed further.

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Comments on B1: Learning and conceptual understanding: beyond simplistic ideas, what have we learned? (Laurence Viennot). Jon Ogborn. Institute of Physics, London.Â She is surely right to insist on avoiding a number of simplistic positions, without losing the essence of what each may have got right. It is indeed difficult, in this kind of work, to avoid the trap of â€œWhat is true is obvious, and what is not obvious is not trueâ€. The most important results, for example the prevalence of â€œlinear sequential reasoningâ€ to which Laurence Viennot draws attention, did not initially seem at all obvious to many of us, but, inevitably, came to seem so more and more as we encountered example after example. Concept learning, also known as category learning, concept attainment, and concept formation, is defined by Bruner, Goodnow, & Austin (1967) as "the search for and listing of attributes that can be used to distinguish exemplars from non exemplars of various categories". More simply put, concepts are the mental categories that help us classify objects, events, or ideas, building on the understanding that each object, event, or idea has a set of common relevant features. Thus, concept learning is a Conceptual understanding, where children can grasp ideas in a transferrable way, can help students take what they learn in class and apply it across domains. Itâ€™s a hot topic in the classroom today, as rote memorization and traditional methods of teaching math are becoming considered insufficient for real-world learning and application.Â As they ask more questions, they understand more deeply. We have to present students with situations with common threads so they can begin to learn patterns and underlying structures by asking questions themselves. Promoting Equity Through Conceptual Understanding. learning with deep conceptual understanding or, more simply, learning with understanding.Â Learnersâ€™ motivation to learn and sense of self affects what is learned, how much is learned, and how much effort will be put into the learning process. The practices and activities in which people engage while learning shape what is learned. Learning is enhanced through socially supported interactions.Â These big ideas lend coherence to expertsâ€™ vast knowledge base; help them discern the deep structure of problems; and, on that basis, recognize similarities with previously encountered problems. Research also shows that expertsâ€™ strategies for thinking and solving problems are closely linked to rich, well-organized bodies of knowledge about subject matter.