

Teaching physics: research-based suggestions and teachers' reactions, toward a better interaction?



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Abstract

How to favour a better interaction between research in physics education and practice? It is argued that this challenge is widely determined by the extent of attention given to “critical details”, that is, some fine aspects of teaching practice that may seem unimportant at first sight although they may have important outcomes. After a first example in geometrical optics, I discuss some possible reasons for the existence of corresponding rituals at the secondary school and college levels. It is shown, with the topic of hot air balloons, that certain rituals in our teaching practices can even make physical theories seem inconsistent. Using these examples, I discuss how we might better highlight the physical phenomena under study, and I give evidence of students’ and teachers’ reactions to the proposed changes. I conclude by considering possible actions relating to teacher training and to assessment*.

Keywords: Physics teaching, critical details, rituals of teaching practice

Resumen

¿Cómo favorecer una mejor interacción entre investigación en Física Educativa y la práctica? Es argumentado que este desafío es ampliamente determinado por el grado de atención dada "a detalles críticos", es decir, algunos aspectos finos de práctica de la enseñanza que pueden parecer sin importancia a primera vista aunque puedan tener resultados importantes. Después de un primer ejemplo de óptica geométrica, comento algunos posibles motivos para la existencia de rituales correspondientes en los niveles de escuela secundaria y el colegio. Se muestra, con el tema de globos de aire caliente, que ciertos rituales en nuestras prácticas de enseñanza aún pueden hacer que las teorías físicas parezcan inconsistentes. Usando estos ejemplos, comento cómo podríamos destacar mejor los fenómenos físicos en estudio, y doy evidencia de las reacciones de los estudiantes y profesores a los cambios propuestos. Concluyo considerando posibles acciones que se relacionan con la preparación de profesores y con la evaluación.

Palabras clave: Enseñanza de la Física, detalles críticos, rituales de enseñanza práctica.

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I. INTRODUCTION

A general concern to attract more students towards learning science now adds up to a less recent effort towards improving students’ understanding in physics. Many investigations, since thirty years, bore on learners’ widely spread ideas and ways of reasoning, some of them being not compatible with accepted physics and very resistant to change. In the same line, students’ views of science have been investigated, showing a very large trend towards what is often called “naïve realism” or supposedly equivalent expressions. Some research-based teaching sequences have been experimented and to a lesser or larger extent evaluated. What are the kinds of research findings that trainee teachers will really put in practice? What do we observe in this respect? Can we suggest some lines of analysis to understand the reasons for the often observed relative failures in this respect [1]. How to favour a fruitful

interaction between research and practice of physics teaching? Faced with such big questions, I have chosen, in this paper, a restricted angle of attack: that of the importance of “critical details”, *i.e.* some fine aspects of teaching practice that may seem unimportant at first sight although they may have important outcomes [2, 3]. A few years ago, Gunstone and White’s wrote [4] p. 302: “The way research influences practice in education is not through discovery of a detailed and specific mode of teaching but through substantiation of principles which pervade thinking about teaching and learning”. My goal is to stress that, for such a “substantiation” to occur, great ideas are not sufficient: A thorough attention to fine aspects of teaching practice is necessary. This topic will be illustrated by an introductory example (in optics), and discussed from the standpoint of evaluation. I will then provide other examples of critical details that are ritual in our teaching practices and I will discuss a few factors that

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probably contribute to explain why they are so common. I will also present some results of investigations in students and teachers that give good reasons to break with such practices. Teacher training strategies will be then briefly discussed, with a particular stress on the question of the teachers' estimation of their students' desires and abilities in terms of "intellectual satisfaction".

II. CRITICAL DETAILS: A PRIORI CHARACTERISATION AND EFFECTS –AN INTRODUCTORY EXAMPLE IN OPTICS

It may happen that, after some investigations centered on learners' common ideas in such and such domains, some apparently small aspects of teaching practice appear as likely to have important effects. In such cases, negative effects are especially pinpointed. Such is the case concerning elementary geometrical imaging.

A. The travelling image syndrome

Some difficulties, now very well known (see for instance Fawaz & Viennot [5], Goldberg & McDermott [6], Galili & Hazan [7]), can be interpreted assuming a model of "travelling image" and its variants. Thus, many students think that a mask put on the centre of the lens would result in a hole in the image, as if this image had travelled (horizontally) in space as a whole.

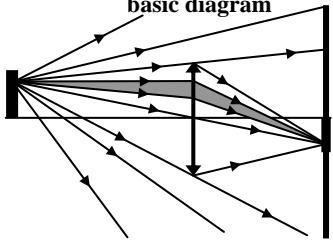
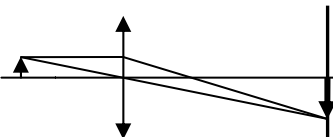
B. Evaluating a suggestion to improve students' comprehension of optical imaging

It is common to stress, when teaching optical imaging, the kind of "classic" diagram shown in Table 1b – showing two "construction rays" only -, without taking time to

explain and illustrate the very principle of optical correspondence between a point A and its image A': any ray originating in the point source and meeting the lens is in line after this lens with the image A'. This classic diagram, although correct (in Gauss conditions), is very compatible with the common and undesired students' views just recalled [8]. It may suggest a global horizontal transport and/or encourage a misinterpretation of the rays drawn on the diagram: There is a risk of seeing them as constitutive of the image whereas they are mere representative of a whole set of rays originating in a point object and hitting the lens.

In this respect, a recent investigation was centered on the evaluation of a possibly favorable "critical detail" of practice, *i.e.* using an introductory diagram to illustrate the role of a thin lens in optical imagery. This "basic" diagram (Table Ia) has two key features: Many rays and beams are represented, as well as some rays which do not impinge on the lens. These undeviated rays are shown to highlight the fact that even the whole lens concerns only a *part* of the flux, thus favoring – supposedly - the idea that a part of the lens can form the image as well. The students with whom it was tried - 20 degree students and 60 trainee teachers - had been taught optics in the previous years in an uncontrolled and probably very classic way, and they were consulted without any new information on this topic. They were divided in two groups. Two classic questions that commonly give rise to the "travelling image" syndrome were posed in two different versions, one for each half group. The two questions were introduced in each subgroup respectively with the classical diagram and with a diagram which was designed to be more explicit about the role of the lens. Table I displays the regrouped results obtained for one of the questions (see more details in Viennot & Kaminski [9]).

TABLE I. Answers of trainee teachers and degree students to the basic (a) and classic (b) versions of a classical question.

<p>Question:</p> <p>A mask is put on the centre of the lens: what can we see now on the screen?</p> <p><i>Exclusives categories ↓</i></p>	<p>(a) Situation introduced with</p> <p>basic diagram</p>  <p>Trainees Degree Together</p> <p>N=29 N=10 N=39</p>	<p>(b) Situation introduced with</p> <p>classic diagram</p>  <p>Trainees Degree Together</p> <p>N=31 N=10 N=41</p>
<p>The same thing or A'B', +sometimes: less sharp, Gauss approx, less luminous</p>	<p>26 8 34</p>	<p>17 2 19</p>
<p>"Travelling image syndrome":A black spot at the centre of the screen <i>or</i> variants</p>	<p>3 2 5</p>	<p>14 8 22</p>

Regrouped results: $\chi^2 = 17.6$, $p=0.001$.

The results are similar for both of populations and more than compatible with the hypothesis that the basic diagram favours a proper understanding of the imaging role of the lens. The high value of the chosen indicator ($\chi^2 = 17.6$, $p=0.001$) is a surprising fact, given the very tenuous difference between the conditions in which the two samples were placed. The point in the present discussion is to stress the often unsuspected importance of reconsidering our teaching rituals, even in seemingly very tenuous "details". This said, it is worth noting that evaluating a critical detail in isolation may require very specific circumstances: for instance, the same investigation at grade twelve turned out to show hardly any effect, in quantitative terms, a fact discussed in [9].

C. Some rituals of teaching practice with potentially negative effects, their possible origins

The preceding example illustrates the potentially negative effects of a precise aspect of teaching practice as well as the probably positive effects of another one. A question is posed as to why some ways of doing in teaching that are to the least problematic are actually not questioned and extremely common, thus deserving the label of "ritual" [10]. This single example suggests many possible factors to explain this fact. To put it briefly, on teachers' behalf: a disregard of learners' common ideas, or a sharing of these ideas, this going with a trend to reify concepts (the travelling image punched when passing the mask), a lack of vigilance concerning over-selectivity in images (only two rays of construction), as well as a consensus to present over-simplified phenomena (no consideration of energy in elementary courses in optics). It is tempting to resort to these strategies because they are sufficient to find the

position and size of the image. Only if other teaching goals are adopted can teachers feel a need to reconsider these questionable aspects of practice.

This introductory example illustrates in fact a good part of the results of the European program Science Teacher Training in the Information Society ("STTIS", coord. Pinto, 1997-2001), results recalled in Appendix). The goal of this investigation was to identify the main tendencies in the ways teachers commonly transform research-based innovation that they are suggested to use. Thus a tendency to consider that "seeing is understanding" is resonant with that of reifying concepts. Or else a wish to work with "clean facts" is coherent with the common practice of presenting over-simplified phenomena, etc.

To give an idea of the generality of such ways of doing, a few additional examples can be discussed, in terms of the tendencies just recalled. This will be done with the situations outlined in figures 1, 2 and 3. As mentioned in the corresponding captions, these examples illustrate respectively (in case of an easygoing treatment of these situations),

- Fig. 1: the trend to reify concepts – see the so-called "materialized rays" – and to disregard the fact that "showing" is not sufficient to understand [11];
- Fig. 2: the risks attached to an over-simplified diagram (see also Colin et al. [12]);
- Fig. 3: the difficulties of understanding an oversimplified situation of friction, (described only at the macroscopic level, whereas a mesoscopic "saw-teeth" model of the concerned surfaces may help students to understand propulsion via friction: see Viennot [13]).

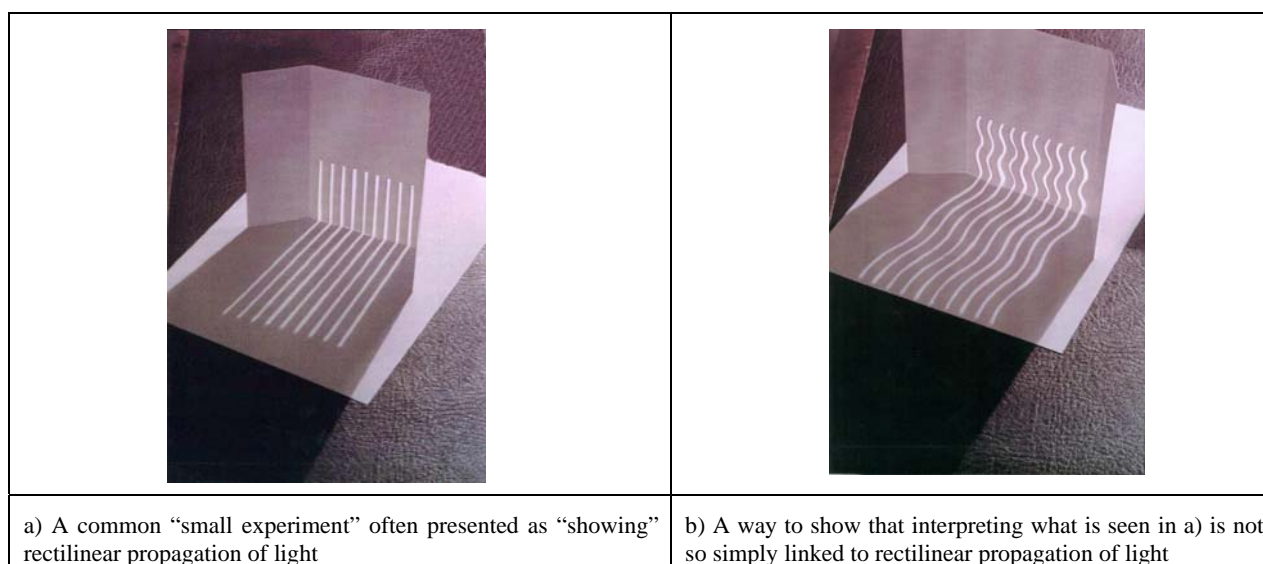


FIGURE 1. An example of a ritual experiment (a) and of a way (b) to avoid oversimplification in this respect. In both cases what is seen is a set of shadows, NOT rays of light [14].

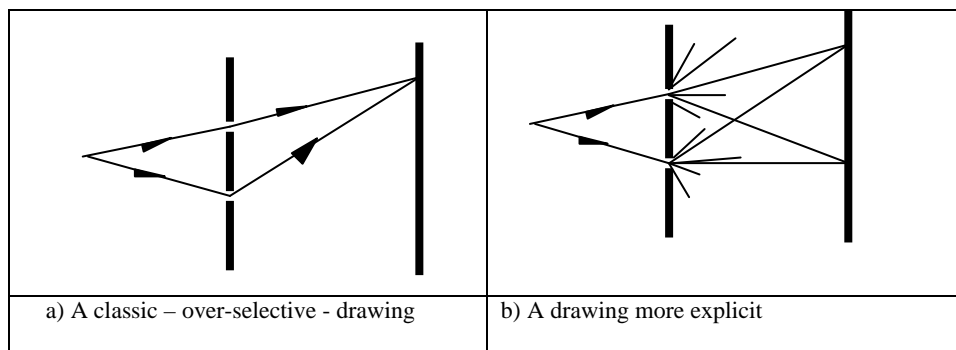


FIGURE 2. A ritual drawing to illustrate wave interferences with Young’s holes (a) and a more explicit diagram (b) which shows diffraction that occurs at the holes’ position, the different status of a path of light after a hole as compared to the ray of light arriving at this hole, and the *backward* selection used to calculate an amplitude at a point on the screen [12].

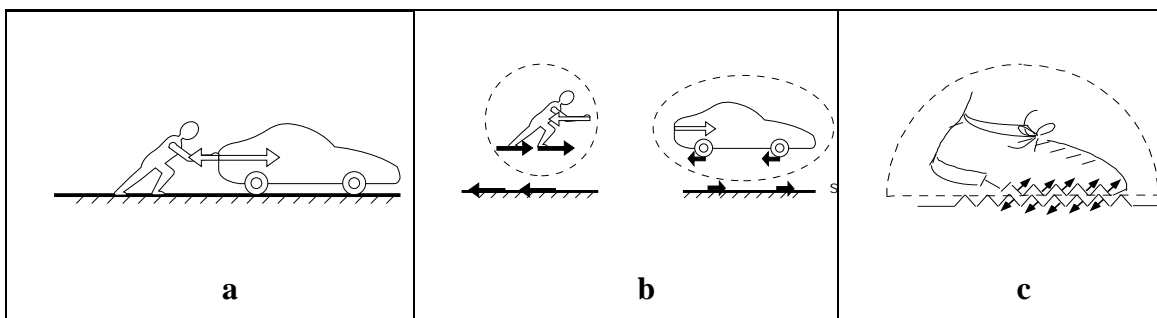


FIGURE 3. Analysing forces in play: In order to avoid a classic error (a), it is useful to provide a more explicit diagram (b), but this may turn out to be insufficient. Indeed when it comes to *explain* the interaction of friction, representing the ground as a smooth horizontal surface is not efficient, contrary to the saw-teeth mesoscopic model outlined in (c) [2].

In all these examples, as said above, there is a large extent of similarity in the possible sources of corresponding rituals. Concerning the possible outcomes, it may happen that a ritual be inefficient in promoting students’ understanding, as is the case of a strictly horizontal and smooth line used to represent the ground. In other cases, an aspect of teaching practice can be likely to reinforce students’ common ideas (the classic diagram and the travelling image syndrome), this without any patent violation of accepted physics. It may also happen that, if not cautiously explained, a situation suggest an inconsistent argument. Thus, presenting the small experiment in figure 1a and letting the students think that it “shows” some rectilinear rays is frankly incoherent with the fact that the source is not in line with the so-called “ray”. Some rituals deserve a thorough attention, in order to avoid similar risks, an idea especially illustrated in the following section.

III. THE HOT AIR-BALLOON: SOME GOOD REASONS TO OVERCOME OUR RITUALS

It is common practice to suggest that in a hot air balloon, the air pressure is the same inside and outside. Again, it will appear that what is “taught” is sheer inconsistency, an inconsistency which has no special relation, this time, to learners’ previous ideas. A classic exercise, indeed, consists in asking students to determine, for a hot air

balloon of volume V , at what temperature T the internal air must be to achieve lift-off, given the total mass of the envelope and of the carried mass. Archimedes’ principle is the target of such exercises. In order to determine the relationship between the density of the internal air and its temperature, it is necessary to know the pressure inside the envelope. The text classically reads something like this: “Whatever the temperature of the air in the balloon, its pressure is the same as that of the air outside it”. This statement, unless it is accompanied by further specification, is very problematic. Indeed, the same pressure inside and outside near each small part of the envelope means that no net force is exerted by all of the gas. So the envelope would be drawn downwards due to the weight of the objects carried and its own weight, and could not but fall straight down [2, 15].

In this example, there is a clash between a global approach of Archimedes’ principle on the one hand, and a local mechanistic analysis, on the other. As will be seen below, teachers do not spontaneously detect the least problem. Traditionally, local and global points of view are not confronted, and the global approach is considered sufficient. But such an approach may entail a shift from using a mean value for the air pressure to considering implicitly this pressure as uniform. This risk is very commonly ignored, and it might be said, in this respect, that most teachers unconsciously contribute to presenting physics as dislocated theory.

Such potential difficulties deserve attention. Thus, the hot air balloon can be presented with a specific treatment,

with the goal of avoiding the inconsistency denounced above and, more positively, to show that physics works. What the global perspective permits us to ignore is the small difference between the gradients of pressure inside and outside the envelope. Admitting that the pressure is the same inside and outside at the aperture level (bottom), it is not consistent to say that the same balance holds at the top of the balloon.

The smaller diminution of the inside pressure with altitude accounts for the fact that this pressure is larger than the external pressure at the top of the envelope, which enables the balloon to stay up in the air (Fig. 4). Of course

the cost of such an approach is not negligible, in terms of teaching time, but neither is it disproportionate.

It is worth noting that, presented with the usual text (outlined above) of an exercise concerning hot air balloons, and with the question: "would you add or change something in this text to make it more clear", this before any discussion, none of the consulted persons (15 first year university students, 32 degree students, 61 trainee teachers) alluded in the least to the problem pinpointed here. But, as outlined below, their had strong reactions after discussion [15].

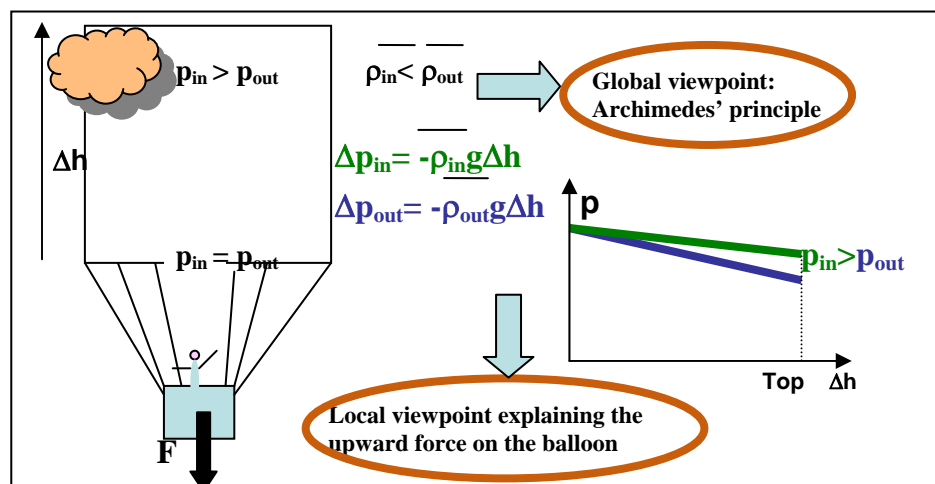


FIGURE 4. Some elements to understand how a hot air balloon holds in the air [2, 15]. F: weight of the system (basket+load+balloon).

IV. STUDENTS' AND TEACHERS' REACTIONS

The just mentioned first year university students individually went through this discussion in a teaching-interview (interviewer: author). At the end, they were asked if this analysis seemed accessible to them. All answered "yes", but sometimes (7/15) said they were not sure they could explain the topic themselves. Also, asked if the discussion was worthwhile, they all answered positively, with comments such as:

- It's always interesting to have exercises like that, sure, explanations, you don't have to give them thoughtlessly, you made me think, me, even if it's difficult, it's fine to think... We learn much more... I have learnt a lot.

Some students (7/15) expressed a feeling of frustration concerning the kind of teaching they had experienced before:

- Why is it the first time someone tells me this?

A student's remark appears as especially relevant to the question of our teaching objectives:

- (Is such a discussion more interesting than doing the classic exercise?) absolutely... provided we are taught how to do it.

Finally, students' last comments were often very gratifying for the interviewer:

- Have you got anything else like that?

In addition, 21 degree students were collectively asked their reactions after a similar session. The great majority [10] declared, on explicit questioning, that they had got *pleasure* in understanding the point addressed and that the session was worth the cost in time.

The same consultation was organized for a group of 15 upper secondary school - math and science - in-service trainee teachers. These teachers attended a session about modeling and relationships between mathematics and physics. Only four of them were physicists. They were presented with the topic of hot air balloons (half an hour), many of them being unfamiliar with this topic. The usual version of the exercise was first proposed, with no reaction on their part, then the more complete discussion outlined in figure 4 was proposed. Finally they were asked to express their reactions with a short paper and pencil questionnaire. The results show that they all considered the discussion worth it for themselves (rated 3 or 4 on a scale 1 to 4), but were less confident that it would be the case for students in their last year at school. Answering the questionnaire after discussion, they suggested to make a distinction, concerning these students, between two possible teaching goals: on the one hand, having a proper idea of what physics is, on the other, understanding how a hot air balloon works. They showed more ready to take the time needed with the first of these goals in mind than with the second (6/15 against 2/15 ratings 3 or 4 – on a scale 1 to 4). Globally, most of them thought that what had been good for them was not really accessible or profitable to

students at grade 12 – whereas most of these teachers were not themselves specialized in physics.

This is not the first time we have found that teachers (or older students) will agree on the value for themselves of an approach which they deny is possible or useful for younger students, this even in cases where there is evidence that the young students are quite comfortable with the suggested approach ([13] pp. 62, 11, 176; [16]).

V. CONCLUSIONS

The main target of this paper is to illustrate how urgent it is to reconsider, in the light of research results, some very common teaching practices, this more particularly if consistency is an important goal of our teaching. Despite the present development of research in science education, there are still many rituals of common teaching practice that are either not discussed, or are very resistant to change, or both. Such rituals can be misleading as regards students' common ideas, or even actively generate a view of physics as inconsistent. In some cases, a common teaching practice limits the adopted approach in a way which screens the power of physics as a unifying description. To detect such rituals and detach oneself from them, general prescriptions such as taking students' ideas into consideration are not sufficient. In addition, these few reflections and results provide the incentive to renounce simplified comments such as "they (*the students*) lack critical sense". It is true that no consulted student detected the potential difficulty linked to a uniform pressure in a hot air balloon, for instance. But no teacher did. Similarly, it is very unlikely that students will spontaneously criticise an over-simplified interpretation of "materialized rays", but teachers in their great majority do not show either a real vigilance in this respect. Rituals installed for a long time seem very effectively to block students' and teachers' spontaneous critical reflection on some topics.

The reasons why such rituals are so resistant to change are multiple. They have something to do with the general tendencies of common reasoning in physics, such as thinking concepts as if they were ordinary objects (e.g.: the rays, an image; see also for the shadows [13]). They might be also be seen as reflecting what are called "common transforming trends" in the STTIS project (coord. R. Pinto). For instance, considering the findings of this project an item such as "observation is valued at the expense of explanation" is more than compatible with the kind of reasoning just mentioned - if a concept is like an ordinary object, why not to show it? Another item – "a one-to-one linkage between a given device and a given didactic approach is observed" – perfectly applies to the case of the optical bench and the ritual focusing on construction rays, both favourable to inducing the travelling image syndrome. As for "the quasi general lack of consideration of links" mentioned in STTIS findings (see also Hirn and Viennot [11]), it is easy to see that this trend does not help one criticize over-exclusive approaches (for instance: only global, as is the case for the hot air balloon). Thus, the main question is not so much one of

finding *the* origin of the observed rituals but rather of finding a way out of so many opposing factors.

Of course, it is natural to suggest some "good practices", in correspondence with the limiting rituals analyzed here: Instead of reifying and "showing" concepts (a materialized ray), we should focus on phenomena (shadows); instead of over-simplifying images (two "rays" in the case of Young's holes and their seemingly individual fate), we should make more explicit the phenomena (diffraction) as well as the subtleties of the theoretical analysis (backward selection); instead of adopting a single angle of attack (global as for the hot air balloon), we should stress the links between different approaches (local and global). Other major lines of reflection and of action have not been dealt with here for the sake of brevity. The importance of a functional approach [2], for example, and the distinction and linkage between quasi-static and non quasi-static transformations [17, 18] also deserve great attention. But as far as classroom practice is concerned, the decisive actors are teachers, this whatever the value of research-based suggestions they are presented with.

What could help teachers to choose more consciously what they do in teaching? Several factors might contribute to this goal.

One is - classically - teacher training. Although it is far from being the only thing to consider, sound training is obviously needed. But, teachers, if mainly presented with general views on Science Education and on Science, might not clearly understand the corresponding stakes. The worst thing would be a purely verbal adaptation to academic training. In this regard, a considerable research effort remains to be made, in order to go beyond the high rate of observed failures and the scarcity of research-based and validated training materials presently available.

An important condition, in this perspective, seems to keep a sharp eye on those small aspects of practice illustrated in this paper, and which seem difficult for teachers to consider. Another factor to be considered is the communication process. Trainee teachers are in a position which is analogous to that of learners at school: they cannot be seen as passive receivers. Keeping to a parallel with the case of younger learners, a problem posing approach seems a priori appropriate to orientate the design of training episodes and materials. The problem in question, I suggest, is precisely how to substantiate great principles (see Gunstone and White's statement in introduction [4]) in detailed actions. More specifically, it may take the form of a question: given this global rationale for such and such sequence, is this particular aspect of practice compatible with this rationale? Or, more abruptly: are we coherent if we think this and do that? A sensible appreciation of coherence between global views and small actions is not straightforward, and it requires education [2].

But training is not sufficient either. As for any potential "learners", teachers are strongly determined by their own feelings towards the goal of the training in which they participate.

In this respect, teachers betray a strong pessimism about their students' abilities. As we have sometimes

heard them say, a new spotlighting of a given topic would be “good for us (*teachers*) but not for them (*their students*)”, a fact sometimes in opposition with experimental results. If teachers do not believe it possible, it is easy to predict that, excellently trained as they may be, they will not even try to raise intellectual satisfaction in their students by the means discussed here. How to enhance teachers' optimism? It is plausible that providing them with the kind of replicable evaluation outlined above, concerning lenses, might be of interest. Trainees who participated in this comparative test were very impressed by the result. But such a demonstration is rarely accessible [9]. For the rest, there is little hope for them to be convinced without trying, which means that they have found a space of time for this activity and have forgotten for a moment the usual stresses on them.

In a more coercive register, a third component is the type of assessment to which students must be prepared. Thus, a recent investigation [19] concerning the French “baccalauréat” (at the end of secondary school) shows that no question in two years (1999 and 2000) asked for a result to be criticized: this throws a very special light on recurrent incantations about “lack of critical sense”. Probably, there might be more effective incentives for assessment to do a better job, if good examples of *precise* wording for this type of question were more abundantly provided by research.

Students on their part, when offered an opportunity to think more deeply about the familiar situations mentioned above, appeared to react very positively. Most probably, their satisfaction has not much to do with the topic in itself. It seems to originate in the feeling that they can master a point, seen from different angles. So it is not so unrealistic to undertake to raise intellectual satisfaction through this type of (exigent) approach, keeping in mind the student's remark: “provided we are taught how to do it.” This very pertinent comment is a good source of inspiration to carry out, or rather to more explicitly orientate, further research based on the ideas developed here, and to favour teachers' information in this respect.

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APPENDIX. MAIN RESULTS OF STTIS REPORT: Investigation on teacher transformations when implementing teaching strategies (Viennot et al. 1999: [20])

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STTIS ("Science Teacher Training in an Information Society") is a research project founded by EU, DG XII,

-Motivation

Even if judged «motivating» by a teacher, be it for the pupils or for the teacher her/himself, an innovation may be transformed to a large extent by this teacher. This may appear at a declarative level, when the debate is about precise teaching actions, or, still more clearly, when such actions are observed in the classroom.

-Topics dealt with versus what is recommended

Some nontraditional topics are neglected, totally (friction) or partly (geometrical condition for vision).

More often, there is a trend to conflate the «new» with the «old».

This may result in hypertrophy (phenomena being taught «per se») and/or incoherence.

This may stem from a view of teaching as necessarily following a unique, traditional, pattern, a wish to negotiate with the difficulties, an incomprehension of the (revisited) content.

-Links - between different approaches or languages, between concepts and activities, conceptual paths - are not put in evidence.

There is a quasi general lack of consideration of links. The recommended order (for instance «from real to ideal»), can be completely reversed in teacher practice.

Often, concepts are taught, and activities are organized, in isolation; the fine-grained specification of a chaining between concepts is not taken-up, at the expense of the global rationale, and of conceptual coherence.

-Learners' previous ideas, language and learning difficulties

These are acknowledged but not actually and consistently addressed.

Problems with teaching materials (texts, images, activities) likely to reinforce these previous conceptions and learning difficulties are not attended to.

-Students' activity: the intellectual structure of the activity is not planned in the same detail as the practical aspects.

This point appears, in our investigations, as a major lack.

Quasi unanimously, only global descriptions of activity are stated by teachers, no fine grained specifications of chaining, links, types of questioning, orientations of debate are specified.

-Prediction, experiment and comparison: an under-exploited cycle

The idea of reasoned prediction before experiment is either totally absent

or envisaged in a limited register: the cycle is not iterated, prediction is not directly followed by any experiment, or else is practiced in the register of motivating discovery;

an interesting exception is observed concerning Color, after training.

-Observation is valued at the expense of explanation.

«Seeing is understanding» seems to be a widely spread slogan.

It might go with the «see what I want you to see» syndrome, and be related to the following point, among other possible causes.

-A wish to start from «cleaned» facts is observed.

This feature is especially striking regarding «Motion and Force»: the suggested conceptual path «from real to ideal» is reversed, the starting point chosen by teachers excluding, in particular, friction.

-A one to one linkage between a given device and a given didactic approach is observed

The maintained use of a classical device drags along with it traditional strategies.

The adoption of a new device can foster the - at least partial - take-up of new strategies.

Designers might usefully take such linkages into account, to avoid rigidity and to favour the implementation of new strategies by backing them up with new devices.

-The «critical details» of a didactic strategy that may deeply affect the impact of a didactic sequence are also those that are the most difficult to communicate to teachers.