STRESSING THE COHERENCE OF PHYSICS: STUDENT JOURNALISTS' AND SCIENCE MEDIATORS' REACTIONS

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Abstract

With this investigation, we sought to assess the extent to which future journalists and science mediators are able to take a positive attitude towards stressing the coherence of physical theories in their chosen profession. To this end, we also examined a second question: how members of this same population react to an exercise designed to stress the value of coherence in physics, as a possible source of intellectual satisfaction. We sought to document the possible impact of the obstacles we had anticipated, and to characterize the students' progression in relation to the goals just described. Our investigation was based on 14 interviews with third-year university students who hoped to become journalists or science mediators. We focused our interaction with them on a specific example in physics, concerning a problematic hypothesis widely used in explaining how a hot air balloon operates. We provided elucidation in the course of each student's intellectual progression during the interview. Finally, we report their value judgements – impressively positive – concerning the two questions outlined above. The results suggest that, despite their low level of specialization in physics, such students can develop, at least in the very particular circumstances described, a critical and positive attitude towards searching for and stressing coherence in physics. They also support the idea that, were a concern for coherence to be taken as a desirable component of a training programme, corresponding teaching-learning sequences should be prepared, designed and evaluated in great detail, to ensure optimum adaptation to each individual's progression.
Key words: *critical analysis, physics education, science mediators and journalists education.*

Introduction: context and general approach

This paper is focused on the training of future journalists and mediators in science, people who will be professionally engaged in popularizing science. This topic has been very little explored in research up to now (McIlwaine, 2007). Our general approach is that one of the aims of popularization of science (POS) should be that of guiding a readership, or any kind of audience, to a certain level of comprehension of the topics broached. Put in these terms, this seems obvious. In fact, what is debatable is *the extent to which* POS might give its audience the feeling of getting more than just the vocabulary relating to a topic and superficial access to the content: a basis on which to reason about the phenomena in question. What is at issue is not merely a single topic but the entire vision of science that is conveyed by POS: a series of isolated 'facts' and explanations, or a more organized and reliable description of given phenomena, in a specified domain of validity.

For more than three decades, a considerable amount of research has been devoted to views of science, to common trends observed in this respect among students and teachers, and to attempts at developing a sound appreciation of how science develops and of the value of its products, in both of the above populations (among many studies: Novak, 1977; Driver & Oldham, 1986; Millar & Driver, 1987; Driver, 1989; Driver, Leach, Millar & Scott, 1996; Brickhouse, Lowery & Schultz, 2000; for reviews, see: Koulaidis & Ogborn, 1995; Abd-El-Khalick & Lederman, 2000). Emphasis has been laid on what is often called 'naive empiricism' or 'naive realism', as well as on the inappropriate view that there is, intrinsically, an absolute and definite truth in scientific achievements. In particular, many important investigations have been conducted on socio-scientific questions (Kolstǿ, 2001a, 2001b; Sadler, 2004; Sadler, Chambers & Zeidler, 2004), which strongly involve concerns about developing students' critical sense. Studies about argumentation and the value of debates often take this approach (for instance Jiménez-Aleixandre, Rodriguez & Duschl, 2000; Jiménez-Aleixandre, Agraso & Eirexas, 2004; Simonneaux, 2001; Zohar & Nemet, 2002). Among their results, a difficulty is observed in students when it comes to building an argumentation with more than a single idea, or to distancing themselves from the written word, in particular papers intended for popularization (Kolstǿ, 2001b; Jiménez-Aleixandre & Pereiro-Munoz, 2002; López Rodríguez & Jiménez-Aleixandre, 2007). Norris and Phillips (1994) found, in a study with grade 12 students, that most of them failed to recognize justifications, causal statements and statements of evidence as such in some media reports. In a further study, the same authors (Phillips & Norris, 1999) observed in secondary school students 'a lack of systematic relationship between students' degree of certainty in their beliefs and the support that the reports offer for those beliefs'. However, Radcliffe (1999), exploring pupils' and more advanced students' understanding of the nature and use of scientific evidence using media reports, provides a less bleak picture. One of her concluding claims is that 'Scientifically literate graduates [...] are able to reason and some overtly recognize details in the limitations of evidence presented. The younger pupils in this study have demonstrated that they have potential for this skill, perhaps more potential than is realized in classroom practice'. In addition, Zimmerman and colleagues (Zimmerman *et al.* 2001) reanalysed some data collected by Korpan *et al.* (1997) about what students want to know when they read popular print media. They concluded, in particular, that: 'The majority of students did mirror experts' emphasis on key elements of method, including characteristics of research design, subjects, and the nature of measures. Encouragingly, they also sought information about control of variables and general characteristics of the data.'

From this stream of research, and beyond variability in research-based conclusions, it clearly appears that there is a need to design and evaluate activities in order to favour and guide students' development in this field (Márquez, Prat & Marbà, 2007; Mazzitelli, Maturano & Macias, 2007; see also: Shamos, 1995; Wellington, 1993; Dimopoulos & Koulaidis, 2003).

With future professionals in the popularization of science, such concerns about the nature of science and critical analysis more generally seem especially relevant. Ideally, among the goals of the training of journalists and science mediators, one should find the ability to criticize what they see, hear and read about science, including from the viewpoint of coherence. This would help such writers or other science mediators to avoid uncritically repeating some ritualistic explanations or fuzzy reports about scientific events, or, in Meyer's terms (Meyer, 1991: 4), being 'a passive journalist'. Such training would be in line with some of the goals classically ascribed to scientific literacy, such as: 'an appreciation of the nature, aims and limitations of science; a grasp of 'the scientific approach' – rational argument, the ability to generalize, systematize and extrapolate, the roles of theory and observation'. (Thomas & Durant, 1987; quoted by Millar, 2005: 18; Millar *et al.* 2006: 1502, see also Jenkins, 1997, 1999).

Here, we focus on an aspect of science that is particularly salient in physics, i.e. the high extent of internal consistency and predictive power that has been aimed at, and widely reached, by the presently available physical theories (Ogborn, 1997; Jenkins, 2007). As Clough (2008) comments (see also: Clough & Olson 2007), 'students who claim that science is tentative without acknowledging the durability of well supported scientific knowledge can hardly be said to understand the nature of science'. The framework of our study is this kind of 'well supported scientific knowledge' dominated by internal consistency and a very close match between observed facts and their theoretical analysis, this of course in a specified domain of validity. This framework is especially appropriate for conducting activities where there are laws and theories that can be used as a basis for reasoning while constituting a strong constraint in possible debates about a physical phenomenon (Ogborn, 2008), particularly when these theories are very concise, as are Newton's classical mechanics and, relying on that, the kinetic theory of gases. Here, we apply the term 'coherence' to reasoning that respects the features of such theories: internal coherence and a very high predictive power.

This study is grounded in a first standpoint (standpoint 1): A reader of popularization papers or books might find some value in having access to a characteristic of physical theories, namely their coherence, as defined above.

Clearly, this standpoint is debatable. It is worth noting a very common view according to which popularization of science should not entail any effort on the part of its target population. It is frequently asserted that, by definition, popularization texts should avoid any formalism (use of formulae and graphics), so as not to lose their readers at once. Thus, discussing the non-academic dissemination of science, Jurdant (1975: 149, in French) writes: 'No particular constraints are used. Popularization prides itself on imparting science without pain. This is in line with its dedication to openness.' In the register of 'Scientific literacy', Millar (2005: 20) wrote: 'the understanding that most people require, however, is qualitative and descriptive, rather than quantitative and detailed. Indeed, too much detail is one of the features that put many students off science'. At first sight, this viewpoint seems still more valid concerning readers of popularization papers. But, although 'qualitative understanding' is far from incompatible with rigour, there is a risk that this idea may serve as an excuse in this respect. Briefly put, there is a tension between our standpoint (1) and the concern for attractiveness. This is a much debated question, at least implicitly through oppositions between precision or detail (e.g. Millar just quoted) and communication.

But no less clearly, if fostering coherence in popularization literature were to be denied any value by student journalists and science mediators, it would be very problematic, if not useless, to train them in this direction. The framework of our questions is simply as follows: if our standpoint (1) were to be at least partially adopted, could we realistically expect their training programme to comprise some components chiming with this standpoint, and if so to what extent? To put it briefly: to what extent are these students open to the idea of fostering coherence in their future professional output? A predominantly negative answer would make the debate just mentioned irrelevant. It therefore seems appropriate to document future journalists' and mediators' reactions in this respect. Clearly, such an investigation cannot be limited to collecting general comments. We therefore chose to ground our data collection in a particular topic in physics. This study was conducted on the basis of 14 interviews with a group of student journalists and mediators in their third year at university.

Research questions

It is *a priori* uncertain whether future journalists and mediators in science are open to the prospect of promoting coherence in their future output: our first and main research question (RQ1), focusing on this subject, will be stated more precisely below.

With student journalists and science mediators, certain potential obstacles (*po* in the following) might interfere with this prospect.

One is the low level of specialization in physics that they themselves may have reached. A poor command of the content they have to deal with in their work might well result in two things: lack of confidence in their own potential for clarification *(po1)*, and a passive attitude to the items of information that they receive and are supposed to transform before communicating them to others *(po2)*. In this respect, we note that the debate about a possible link between argumentational abilities and command of content is still open. A relationship between these two aspects is denied by Kuhn (1991) and Perkins, Farady & Bushey (1991), but some authors take a less clear-cut position (Means & Voss, 1996; Sadler & Donnelly, 2006; López Rodríguez & Jiménez-Aleixandre, 2007). This means that the low specialization of future journalists might well hinder their ability to criticize what they hear or read, and therefore lower their valuation of coherence. This remark echoes Meyer's comment (Meyer, 1991: 4): 'To defend against being manipulated, the media need more self-confidence, and the best route to self-confidence is through knowledge.'

Moreover, now in direct relation to our standpoint 1, students might think that their future readers would not particularly enjoy being conducted along a relatively rigorous intellectual path *(po3)*. In that case, their wish for a wide readership might induce them to be less demanding in terms of a search for coherence. Is it possible to overcome this classic obstacle that consists in seeing rigour and attractiveness as two incompatible things?

Most probably, to overcome such an attitude, student journalists and science mediators should consider that a degree of intellectual rigour can give rise, *per se*, to a type of pleasure, which we define for the present purposes as 'intellectual satisfaction' (Viennot, 2005, 2006); it is a feeling linked to the impression of having understood a complex topic to a certain extent, one that can be identified quite clearly, this being accomplished with a good quality/cost ratio. To believe that such a feeling exists, the first condition, we suggest, is having had access to this kind of satisfaction oneself.

Consequently, and this is our second research question (RQ2), we examine to what extent students may derive intellectual satisfaction from a particular teaching-learning situation, despite the possible obstacles (*po1, po2*, *po3*) just described. This affective aspect is not envisaged here as a component of motivation likely to influence learning (Keith, 1993; Pintrich, Marx & Boyle, 1993; Rhöneck, Grob, Schnaitmann & Völker, 1998; Bandura, 2001, Pajares and Schunk, 2001; Cassady and Johnson, 2002; Laukenmann *et al.*, 2003, Cavallo *et al.,* 2003; Glynn *et al.*, 2007), but as an aspect that may evolve during a learning process. Thus, rather than seeing it as a likely condition for learning, we consider the reverse influence: is it possible that a better understanding of a non-trivial topic can raise intellectual satisfaction in these students? If so, to what extent?

In order to shed some light on this point, we thought it necessary to take some risks in the investigation, by bringing relatively demanding reasoning into play. The subject matter involved in our investigation is deliberately far from obvious. At least this choice should provide a counter-argument to a possible objection of obviousness. Indeed, in order to assess students' reactions to a possible component of training, we thought it inappropriate to just leave them alone with a text and a few written questions to answer. As explained below, our experiment brought strong guidance to bear. This circumstance may be seen as a sufficient reason for students to be satisfied. But then, it should be considered that this effect occurred apropos of a tough topic, without being screened by the conceptual complexity. Denying that such a result can have any informative value would come down to a very optimistic view of the potential attractiveness of science: whatever the difficulty of a topic, students could be pleased by a personal discussion about it. Here, our purpose was to appreciate their potential in this respect, by illustrating in detail their individual intellectual paths, given various obstacles.

Our first research question (RQ1) can now be rephrased as follows: we intend to assess the students' views on the prospect of promoting consistency in their future practice, for such and such an audience, this at the end of an interactive session with an experimenter. We intend to characterize a provisional state of mind, trying to pinpoint students' reactions at this particular moment, after a discussion that may have afforded them a certain intellectual satisfaction.

The central question here is not the extent to which they are realistic about a type of writing for a paper intended for such and such a readership. Similarly, we do not mean that the intervention brought to bear in this investigation should illustrate the quintessence of appropriate training. The delicate compromises between the above-mentioned contradictory stresses have to be made by professional journalists, who also have to guide beginners in this field. In this respect, we do not consider that possible enthusiasm in a future journalist for a kind of extreme formalism would be an appropriate attitude. Such a tendency should be rationally examined and put in perspective, under the guidance of professionals. Thus, the teaching-learning interview used here is not to be seen as an innovative sequence that we evaluate, but as an instrument to investigate students' reactions to our research questions.

Before elaborating on the design of this study, we outline, in the next section, some results of previous investigations that served as a basis for planning the research described here.

Background

We considered the results of some preliminary investigations (Viennot, 2005, 2006; Mathé, 2006). The aim was to assess students' reactions when confronted with a seemingly inconsistent but common hypothesis introduced in an exercise about a hot air balloon (the inner and outer gas pressure would be the same, see for instance Giancoli, 2005), and when engaged in a fairly rigorous analysis of the content involved. The first students consulted in these investigations were at the beginning of their university career, or in their third year. They were conducted, individually (1st year) or in groups (3rd year), through a dialogic session during which the experimenter provided questions and input, with a view to criticizing the problematic hypothesis and reaching a deeper understanding of the topic. The students' very positive reactions contrasted starkly with the general pessimism expressed by many teachers consulted during the same study. Unanimously satisfied at having themselves reached a better understanding of the physics involved, these teachers frequently expressed doubts as to the potential value of such an approach, as an echo to the complaints about 'students' lack of critical sense' and to the no less common prediction: 'it's too difficult for them, it will confuse them'. As for the students, they participated in the proposed dialogue very actively and, after varyingly halting progress, seemed to have reached a satisfying sense of comprehension. They were almost unanimous in expressing grateful approval and sometimes anger about previous teaching: 'Why hasn't anyone told me this before?' Similar results were obtained by Mathé (2006) who replicated this experiment with a few students at a still lower level of specialization: the third level at university in a course for primary school teachers. It is worth noting that *all* the students consulted, if judged on their first spontaneous reaction – i.e., briefly put: none at all – when faced with the problematic hypothesis, could be said to have adopted a deferential attitude to the text. This was also the case of all the teachers consulted (n=96).

With these results in mind, we thought it was *a priori* possible to confront future mediators with a relatively demanding dialogue oriented towards the search for coherence, in order to document the research questions enunciated above. Such students shared at least their low level of specialization in science with the groups involved in the studies just outlined, the results of which, in our opinion, were a clear encouragement to envisage an interview involving considerable input from the experimenter.

The experimental design: overview

We adapted the earlier experimental design to third-year university students reading for a degree in science mediation, destined to become journalists or mediators in various institutions in charge of disseminating science in non-academic contexts.

We drew on the previous investigation to frame the experiment. We chose the same topic – a hot air balloon – because it requires a significant effort of abstraction, yet is accessible with limited formal tools, linear functions in particular. The text under scrutiny was a simulated popularization paper on this topic, comprising the usual problematic hypothesis.

A teaching interview was proposed, with a view to searching for a coherent analysis of this physical situation. By 'teaching interview' we mean a one-on-one interaction conducted in line with the 'teaching experiment' recommended by Komorek and Duit (2004). For our purposes, each of these 'teaching interviews' (for the sake of brevity, we call them 'interviews' in what follows) is 'a discussion oriented towards conceptual acquisition, one that is strongly structured and guided, and allows students to evidence their initial thoughts and their reactions to diverse questions and requests' (Bradamante & Viennot, 2007). The interviewer – one of the authors, a physics teacher at university level – was not the teacher of these students.

As in the previous investigations, a certain intellectual satisfaction was supposed to be generated by a confrontation between two viewpoints, one local – allowing detection of the problem – the other global, in this case Archimedes' theorem (see below for more details). We considered not only the students' first reactions when presented with the suspect text but, more importantly, the changes in these future mediators during and after the intervention.

In line with the research questions enunciated above (RQ1 and 2), we report here on the future mediators' reactions when they were guided along this rigorous intellectual progression.

More specifically, we searched for material with which to document the following points:

- When they were asked to give a critical analysis of an apparently unproblematic paper, and helped to identify the actual problem, would the future mediators change their approach to this text? We focused on the ways in which, when the interviewer called on their need for coherence, they reached a new vision of the problem, and took a varyingly active part in the search for a deeper analysis. In particular, we searched for arguments inducing them reconsider the proposed text.

- We also researched the degree of pleasure – a term we use to refer *here* to intellectual satisfaction – that the students had derived from the session, and could explicitly express at the end of the interview. Indeed, as suggested above, it is presumably a relevant indicator of the direction that they might take in their future professional activity, if trained in this approach.

- Did they intend to use such an approach in their future profession? Did they consider it important to lead readers of popularization papers to the same kind of analysis? If so, which readership did they consider amenable to such an approach?

Considering the factors that might be involved in such cases, whether in hampering or facilitating interaction with the interviewer, and/or in influencing their final ratings, we conducted the investigation as follows:

- We researched some clues indicating a greater or lesser familiarity with formalism (*po1*), although we did not intend to *visibly* test this aspect, in order to avoid accentuating possible feelings of inadequacy in this area. Where such feelings were explicitly expressed, we collected the corresponding statements. Along the same lines, we noted some references to knowledge from everyday life, or more generally to a view about the concepts involved, that served either as aids or as hindrances to reasoning.

- We noted some signs of a strong disinclination to criticize the written word (*po2*), or, sometimes, of the opposite attitude.

We do not intend, with such a small sample, to give evidence of correlations between such and such a factor and the students' final assessments. But we consider it useful, at this exploratory stage, to draw attention to these features in the students' reactions, in order at least to test some common clear-cut views such as, for instance: 'A search for coherence can only be appreciated by brilliant students'.

We first present a content analysis of the physical situation used in the study, then we report in more detail on the investigation conducted with student journalists and science mediators.

A hot air balloon: some elements of a content analysis

A problematic hypothesis

As pointed out above, it is common practice to suggest that in a hot air balloon, which is open at the bottom, the air pressure must be the same inside and outside. A classic exercise consists in asking students to determine, for a hot air balloon of volume V, what the temperature T of the air in the balloon must be to achieve lift-off, given the total mass of the balloon, its load, and the temperature outside. The aim of such exercises is to work on Archimedes' principle. The pressure inside the balloon is used, with the required density, to find the necessary temperature. The text classically reads something like this: 'Whatever the temperature of the air inside the balloon, its pressure is the same as that of the air outside it'. This statement, unless accompanied by further discussion, is very problematic. If there were the *same* pressure inside and outside near each small part of the envelope, it follows that *no net force* would be exerted by all of the gas. Inevitably then, there could be *no upthrust*. On this account, the balloon would simply fall to the ground due to its weight. The hypothesis cannot be valid.

In this example, there is a clash between a global approach to Archimedes' principle on the one hand, and a local, mechanistic analysis on the other. As pointed out earlier, teachers do not spontaneously detect the slightest problem. Traditionally, local and global points of view are not confronted with one another, and the global approach is considered sufficient. But this has allowed a shift from using a mean value for the air pressure to implicitly considering this pressure as uniform. This risk is very commonly ignored, not only by teachers but also by writers of popularization papers, when they propose an explanation of what a hot air balloon is (e.g. Maury, 1987: 67).

Note that another approach could also be used to show that there is a problem with the suspect hypothesis. It refers to spherical symmetry: if all of the gas, inside and outside the envelope, were at the same pressure, the situation would be, in this respect, isotropic. Concerning the forces exerted by the gas, no direction is favoured over any other; no upthrust could be expected. It is also possible to argue, in a slightly more analytical way, that the outer air alone, in case of such a spherical symmetry, would exert a zero resulting force, because summing up all the contributions on the envelope would give a zero resulting force. The same argument could be used concerning the inner air. Again, the suspect hypothesis turns out to be invalid.

Reconciling two viewpoints on the physical situation

In line with the goal of showing that physics is a coherent set of theories, one approach seems worth considering: using more than one argument; that is, in this case, linking the local and global aspects of the physical situation analysed.

The problem with the hot air balloon is that one argument – the global one, using Archimedes' principle – is not enough, if one wants to avoid the inconsistency pointed out above and, more positively, to show that physics works. What this global perspective lets us to overlook is the small difference between the pressure gradients inside and outside the envelope. Admitting that the pressure is the same inside and outside at the aperture level (bottom), it is inconsistent to say that the same balance holds at the top of the balloon.

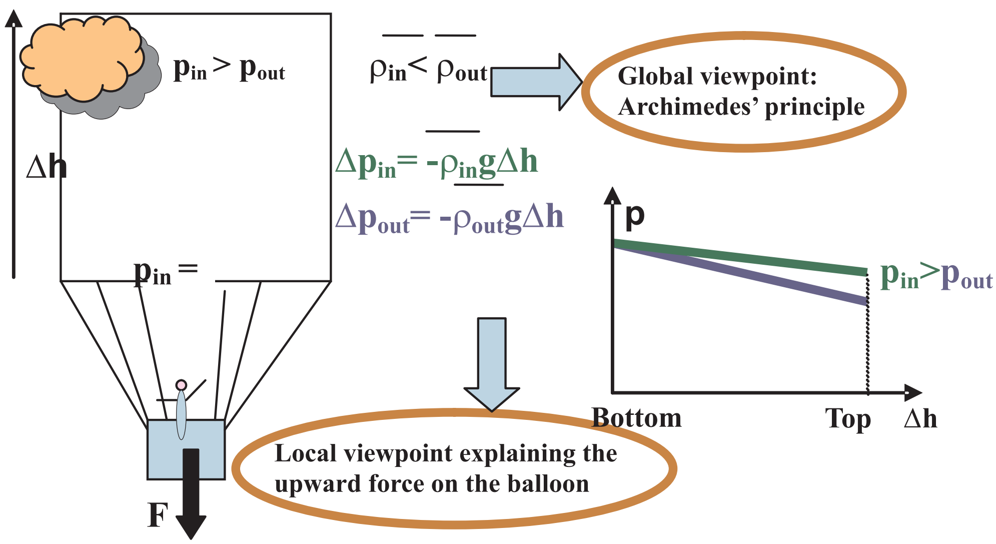

Figure 1. Some elements needed to understand how a hot air balloon stays in the air; F: weight of the system (basket + load + balloon).

The smaller diminution of the inside pressure with altitude accounts for the fact that this pressure is greater than the external pressure at the top of the envelope, which enables the balloon to stay in the air (figure 1). Note that, for a simplified analysis, a cubic form can be proposed for the envelope, without invalidating any of the basic elements proposed to explain the physical situation. Such is the conceptual content that we chose to bring to bear in our investigation with future journalists and science mediators.

Methodology of Research

Sample

We surveyed 14 students who were enrolled in a course to prepare for professions in scientific mediation. This course is open to students who have a diploma in science, obtained at least two years after the French baccalaureate. The last diplomas that the students obtained before they joined the course were diplomas in biology ('β' in the following, n=7), physics ('φ', n=4), archaeology ('α', n=1 master's degree), scientific and technical information ('ι', n=1), and mathematics ('μ', n=1). This information is recalled in Tables 1 and 2, with names for the corresponding students (NB: their names have been changed in this article).

As we chose to conduct an in-depth analysis of each student's intellectual pathway, we considered that the size of the sample was suitable for this investigation.

The interviews: detailed description

Before each interview, the students were presented with a simulation of a popularization article, written by us, about the functioning of a hot air balloon. The text, about half a page long, mentioned the usual hypothesis (see Appendix 1), thus echoing what can be found in popularization literature (e.g. Maury, 1987: 67). They were asked to read it carefully and to answer, independently and in writing, the following questions, which were similar to questions they are asked on their normal course:

1. Do you think this text is appropriate from the following points of view: Its readability? Its explanatory power? Its consistency? Its accessibility?
2. Would you wish to add any details to the text? Which?
3. Would you wish to change any passages? Which? How? And why?
4. Would you like to delete any passages? Which? Why?

Through these questions, we intended to project the students into their future profession, and to put them in a position where they had to clarify a topic. Although the focus of our investigation was on coherence, the students' attention was not directed exclusively to that point, as the set of questions comprised the usual aspects that a science mediator would be expected to face. We did not expect the students to say that the text was 'wrong'. Rather, we gave them an opportunity to criticize it and add details that would make the physical situation more understandable. For instance, they might have proposed changing 'As for the pressure, it is the same inside and outside' to 'The inner and outer mean pressures are considered to be very close'.

After this time for independent thought, the students were invited to start a dialogue with the interviewer. These interviews were intentionally directive, while still being open to students' digressions and questions, but keeping to the general framework that is presented below. The aim was not to observe the students trying to solve the problem by themselves, nor to investigate their views about pressure or whatever in detail; but to guide them in the somewhat subtle reasoning outlined in figure 1. During these interviews, the interviewer focused on, and adapted the guidance to, the receptiveness of the students to the warning signals they were given, their comments once the problematic hypothesis was detected, and their reactions when prompted to reason on the basis of simple but consistent formal elements. The interviews were audio-taped and transcribed.

The interaction with the students was organized in three main steps, each divided into a number of items.

Step 1

a. Ask for the student's opinion of the fact that the pressures inside and outside are said to be the same.
b. Try to invalidate this hypothesis with the two reasons presented in introduction – one in terms of symmetry, and the other, local and mechanistic argument.

c. Explain Archimedes' principle to bring out the idea that pressure depends on altitude (z) and density (ρ).
d. Draw a graph of the external and internal pressures versus the altitude and stress that there is a difference in pressure, in particular at the top of the envelope.
e. Link this difference in pressure to the resulting upward force of the action of the air inside and outside the envelope – which is easier with the model of a cubic balloon.

Step 2
Here we tried to collect the students' value judgements about this more rigorous approach:
a. Ask if everything has been well understood.
b. Ask if they feel able to explain it over again to someone else.
c. Ask what kinds of public could be presented with this problem.

Step 3
a. Ask if they appreciated this critical dialogue, if they derived pleasure from the whole interview, and how much value they attached to the refined explanation. Ask them to rate the pleasure they derived in this respect on a scale from 1 (low) to 4 (very high).
b. Similarly, ask them to evaluate a kind of 'interest / cost in time' ratio on a scale of 1 (low) to 4 (very high).
c. Ask if, as journalists, they would consider it worth introducing diagrams, graphs, formulae, etc. to explain the functioning of the hot air balloon as done just now, or if they think it would overburden the reader to no useful purpose.

We analysed the interviews by focusing on comments relating to a series of themes (see below, 'Main results') which echoed our research questions. For each theme, we provide some sample comments and we estimate, for each student, whether he/she expressed him/herself at least once in a way that we thought corresponded to this theme. The degree of similarity was assessed by negotiation between the authors on the basis of their interpretation of the students' comments.

Given the relative complexity of the physics and the variety of the intellectual paths observed, we chose to code our results in terms of presence/absence of a given theme in the students' comments while pinpointing the step at which this event occurred. We also indicated whether the theme was implicitly or explicitly represented in the students' talk. For instance, a poor command of the content could be observed through the students' hesitations, or admitted by the student him/herself. Although obviously reductive, this 'presence / absence' approach allowed us to observe some common aspects in the intellectual paths of the students. In order to (partially) compensate for the corresponding limitations, we quote the students' responses extensively.

Results of Research

Analysis of the interviews

At the preliminary stage of their analysis, when the students were asked to think independently about the article, most of their remarks concerned the journalistic style of the article, for example: '*As for the pressure'* is really heavy from a journalistic point of view.' This is not surprising, since style and readability are given high priority in their training.

Not a single student detected the problematic hypothesis, as in our previous studies. None alluded, to any extent, to a possible problem of coherence. Thus, the results confirm that the population consulted is, in terms of spontaneous reaction, far from showing an ability to make a critical analysis of the paper, on the basis of physics (*po2*). However, it is worth noting that their attention was not focused on the suspect hypothesis at this preliminary stage.

Five comments concerned the need for a certain amount of knowledge, if readers were to understand the topic, and a problematic dimension of simplicity/complexity:

-'I'd add to or I'd simplify the passage about Archimedes' up thrust which is too complex for an inexperienced reader. The notion of fluid: which fluid? Density, what is it?'

-'Definitions of pressure should be added because you can't see the link with the functioning of the hot air balloon if you don't know what pressure is.'

Given the small number of students who seemed interested in what their readers might know about physics, it seems that the student mediators were not much concerned, at first sight, by the kind of comprehension that might be expected with this paper.

Concerning the remainder of the interview, the themes orienting our analysis were organized in the following three sections, presented here in the chronological order of the interview:

a. Factors that seem *a priori* to hinder or favour an active search for coherence (relating to *po1* and *po2*);

b. Awareness of the incoherence and critical attitude: individual progressions;

c. *A posteriori* attitudes, assessments and desire to reinvest the process (relating to *RQ1* and *RQ2*).

The corresponding results, explained in detail below, are outlined in two tables.

Table 1 outlines the results for themes that are directly connected to our main question, that is: can such students derive – *a posteriori* – intellectual satisfaction from an accompanied progression towards coherence, despite *a priori* obstacles (col. 2, 3, 4), such as possible awareness of their weakness in physics, and their initial absence of critical or questioning remarks about the article (section a of the interview)? Their final ratings and their possible desire to reinvest the outcomes of this experience in their future profession assessments (section c) are also summed up in Table 1 (col. 5, 6, and 7).

Table 2 displays some features that characterize the students' intellectual paths *during* the interview (section b): did they realize that the hypothesis was problematic, and if so, how? Did they clearly change their attitude and become overtly independent in their reasoning, and if so, when? In particular, we searched for clues concerning this question: will the detection of an incoherent hypothesis be enough to foster a new attitude in students who were initially rather passive towards the written word?

Our results were as follows:

a. A priori hindering or favourable factors

During the interviews, we detected several clues indicating difficulties, or proficiency, in physics and mathematics (*po1*). We shall distinguish the clues to levels of competence detected by us from explicit statements made by students, i.e., comments made spontaneously by the students about their own competence. As far as physics is concerned, what is clearly observed is often a lack of command, but in the context of this investigation, it is not always easy to determine which difficulties relate to physical concepts (e.g. pressure), possibly linked to common experience, and which are mathematical difficulties. For example, one student put forward what seemed to be a mathematical reasoning that turned out to be based on a misunderstanding of pressure phenomena. When reminded of the basic formula of fluid statics $\Delta p = -\rho g \Delta z \Delta p = -\rho g \Delta z$ (p for pressure; ρ for density; g, the acceleration of gravity; z for altitude) and asked to draw the curve of the external pressure, Anna said:

Anna: Well, the pressure will increase with the altitude.

But when the interviewer asked her what difference there was between sea level and the top of a mountain, she – rather surprisingly – linked the thinness of air to higher pressure:

Anna: Ha! Stupidly I thought 'less air, so higher pressure'.

Int.: Why?

Anna: Well… When you can't breathe you feel 'oppressed'.

We propose a tentative classification in this respect (col. 2 and 3, Table 1), given that what seems important here is not a precise diagnosis of such aspects, but rather confirmation of whether or not the interviewees may *a priori* have had a handicap, one with a possible psychological component. The comments quoted below, mainly collected during the first phases of the interview, suggest the existence of actual difficulties among the students, but it was sometimes the case that the students spontaneously expressed, retrospectively, how they had felt at the beginning of the interview: such cases have been coded separately in Table 1.

- Level of command of the linear function

Nearly all the students (n=11) showed many difficulties when they were reminded of the formula $\Delta p = -\rho g \Delta z \Delta p = -\rho g \Delta z$ and asked to represent inner and outer pressures as a function of altitude. These difficulties were especially linked to the shape of the curve. The first curve, representing the external pressure, was a problem for six students (Dima, Céline, Laura, Emmanuelle, Adeline, Marion), concerning the change in pressure (increasing or decreasing function) and/or the aspect of the curve (parabola-like, straight line…):

> ***Int.:*** How would you draw the curve of the outer pressure as a function of altitude?
>
> ***Dima:*** Well, if it decreases at the same time and if it's linear… Well, I don't know whether it's proportional or not… It would be something like this (*she draws a straight line sloping downwards*).
>
> ***Int.:*** You're not sure it's linear?
>
> ***Dima:*** No I'm not certain. Actually I don't know at all.

Another problem appeared when they were asked to draw the second curve representing the internal pressure in relation to the external. Ten students had difficulties in determining their relative positions, after having been reminded of the lesser density of the air inside. Four of them thought that the density of the internal air being lower than that of the external air, the internal pressure would decrease more rapidly than the external pressure:

> ***Int.:*** Try to draw the curve of the inner pressure. What has changed?
>
> ***Laurence:*** […] It will be more sloping because the density has decreased.

Only three of the fourteen students interviewed (Damien, Nuno and Ludovic) seemed relatively at ease in drawing the two curves as a function of altitude.

These results are outlined in Table 1, col. 2.

- Level of command of physical concepts

Although this study is not focused on students' conceptions, we examined how their views, possibly originating in everyday life experiences, might influence their approach to the problem.

Thus, early in the interview six students (Anna, Carine, Côme, Laurence, Adeline, and Ludovic) expressed doubts about or rejection of the idea that pressure decreased with altitude. We also observed that six students associated Archimedes' upthrust primarily with water. This view even cast doubt on the existence of Archimedes' upthrust in the air:

> ***Int.:*** Do you know where Archimedes' upthrust comes from? Do you know why it's a vertical upward force?
>
> ***Anna:*** Well, yes, for water, because we studied it in grade 12, but for air it seems more abstract.
>
> Only three students did not show particular difficulties with the physical concepts used here. One of them stands out in the group with a very fine intuition about the phenomenon under study, yet with no knowledge of any formalism:
>
> ***Int.:*** How do you define pressure?
>
> ***Emmanuelle:*** I don't know… I know that at the surface of the water, it's one bar, and I know that you gain another bar every ten metres and I know that it also decreases when you go up, I think. When you go up, the pressure decreases, doesn't it?
>
> ***Int.:*** Yes, it does.
>
> ***Emmanuelle:*** But the pressure depends on the force… the gravity… [...] something like that multiplied by… maybe the density of the fluid. [...] for example, the pressure in water increases a lot more rapidly than in the air so I think it also depends on the attraction and…

you know what I mean? Matter. Well, that's how I imagine it. But don't ask me the formula because I have no idea at all!

Overall, the difficulties observed in the interviews with the students, both those linked to the graphic representation of linear function and those linked to the physical concepts used here, confirmed that we were dealing with a population that was not highly competent in mathematics and physics.

Furthermore, this state of affairs was spontaneously expressed by some students (n=4), although we did not try to make them comment on that point. Here are some examples of students overtly expressing the feeling that they were not 'good' at physics:

- Côme: I have no idea. I've never been good at this stuff…

- Laura *(who has a Master's degree in physics):* […] That's true, I should know but I don't.

These results are outlined in Table 1 (col.3).

- Attitude at the beginning (steps 1a and 1b): acquiescence or free search for coherence?

These results are outlined in Table 1. The fourth column displays the students who showed school-type reflexes and / or uncritical confidence in the content of the article, as exemplified just below.

School-type reflexes:

Four students (Damien, Anna, Adeline, Marion) often tried to refer to their memories of school learning in order to recall a formula or a result seen in class. At least at first, this – not very surprising – attitude seemed to get the better of the reasoning. We found that most of the students' attempts to remember their lessons failed:

Int.: He says that the pressure inside and outside are the same. Do you see a force that could make it stay in the air?

Damien: It would be Archimedes' upthrust… That says that the force equals the volume… uh… the density… I must remember… It's the density of the fluid displaced. But I don't know how it can help explain things.

Uncritical confidence in the content of popularization articles

Another potentially blocking attitude was spotted in nine students: the idea that what is written in a popularization article must be right.

Thus, when we asked Côme and Laura to explain the principle of the hot air balloon in their own way, they first used their own words, but as soon as they came up against a difficulty, they extracted sentences directly from the article, as if they considered it the only reliable source of information.

In contrast, some students (n=5, Table 1, col.4: Nuno, Ludovic, Laurence, Marion, Emmanuelle) made efforts to analyse the text and comprehend the topic from the beginning, although they did not identify the problematic hypothesis. This was particularly the case of one student, Nuno, who showed a great desire for coherence by asking many questions to try and understand what the author meant. With his strong will to understand, he reacted rapidly to the interviewer's comments and decided that there was an incoherence in the text:

Nuno: Here he says that the pressure is the same inside and outside… But in that case, what could distend the envelope if not the pressure on one side or the other? There's something wrong here! […] the weight of the envelope prevents it from remaining distended like that. If there's no force that distends your envelope, what can do that? […] there must be a higher pressure inside!

Laurence and Ludovic also made these remarks as soon as they were explicitly asked their opinion of the hypothesis:

- Int.: What do you think of this sentence?

Laurence: Is it a postulate, given without any real explanation? […] This sentence seems to mean that no movement is possible.

- Ludovic: As the air outside is not heated, the external pressure can't be the same as inside.

To sum up, it appears that at the beginning of the interview, only five students clearly showed an independent attitude and seemed to desire to improve their understanding of the problem. At the same stage, by contrast, nine students might be said to have taken a passive stance toward the text.

Table 1. Aspects of students' reactions at the beginning (col. 2, 3, 4) and at the end of the interview (col. 5, 6, 7, 8).

Name and "scientific origin" (see text)	Command of the linear function[1]	Command of the physical concepts[1]	Desire for coherence and critical sense before step 1b [2]	Intellectual satisfaction [3]	Worth it despite the time it took? [3] *(Duration of the interview)*	Would plan to write a paper with the same type of analysis YES: n=14	
						For what kind of readership?	Δ or no Δ [5]?
Nuno (β)	+	+	+ and '-'	3	4 *(45 minutes)*	From LSS [4]	Δ
Ludovic (β)	+	- and '-'	+	3	3 *(45 minutes)*	From LSS [4]	No Δ
Laurence (β)	- and '-'	- and '-'	+ and '-'	3	4 *(33 minutes)*	From HSS [4]	Δ
Carine (β)	-	-	-	4	4 *(34 minutes)*	From LSS [4]	Δ
Adeline (φ)	-	-	- and '-'	3	3 *(44 minutes)*	From LSS [4]	No Δ
Céline (β)	-	-	-	3	4 *(47 minutes)*	From LSS [4]	No Δ
Côme (ι)	- and '-'	- and '-'	-	4	3 *(27 minutes)*	General public	Δ
Damien (β)	+	-	- and '-'	3	3 *(32 minutes)*	From LSS [4]	Δ
Dima (β)	-	-	- and '-'	3	4 *(25 minutes)*	From LSS [4]	Δ
Anna (μ)	-	-	- and '-'	2	4 *(31 minutes)*	General public	Δ
Marion (φ)	-	+	+ and '-'	4	4 *(47 minutes)*	General public	No Δ
Emmanuelle(α)	-	+	+	4	1 *(55 minutes)*	General public	No Δ
Laura (φ)	- and '-'	- and '-'	-	3	3 *(39 minutes)*	General public	No Δ
Thomas (φ)	-	-	-	3	3 *(26 minutes)*	Scientifically literate	Δ

1 As far as command of the physical concepts and of the linear relationship can be separated (see examples in text), a 'minus' (or 'plus') sign indicates the emergence of difficulties (or none) in one of these respects; inverted commas indicate that the student him/herself explicitly expressed such difficulties.

2 Students' comments referred by us to one of the two labels 'school-type reflexes' and 'uncritical confidence in the content of popularization papers' (see text) are marked with a 'minus' sign; an independent attitude from the start is marked with a 'plus' sign (see examples in text). Inverted commas indicate that the student him/herself explicitly expressed a lack in this respect.

3 Rated from 1 (low) to 4 (very high).

4 These students think it is possible to propose such an approach to students from lower (LSS) / higher (HSS) secondary school.

5 'Δ' indicates that the students would use $\Delta P = - \rho g \Delta z$ and graphs to explain the functioning of a balloon. 'NoΔ' indicates that they feel able to explain it with words, illustrated by diagrams, but without formulae and corresponding graphs.

b. Awareness of the problem: individual progressions

As explained above, we used two strategies to draw attention to the problematic aspect of the sentence in the article 'As for the pressure, it is the same inside and outside'. We first proposed that the students think about what would happen if the pressure were uniform inside and outside the envelope, in other words if the entire situation were spherically symmetrical, apart from the basket. Thus, concerning the interaction between gas and the envelope, no direction could be favoured and no upthrust could be expected. The second strategy appealed to a mechanistic reasoning. We asked the students to consider the local pressure forces exerted on both sides of each small part of the envelope. If the pressures were the same inside and out, even considering a pressure gradient, the students should arrive at the conclusion that the resulting force applied to the envelope would be zero. All of the students reacted positively to our intervention, at different stages and to varying extents. More specifically, each step of the interview affected the students as follows.

- Early awareness of the problematic hypothesis

As soon as their attention was drawn to the suspect hypothesis, three students (Table 2, col. 2: Nuno, Ludovic, Laurence) seemed ill-at-ease with the explanation proposed in the article. Thus, as shown in the quotations above, they detected, more or less clearly, that something was wrong even before we set up the strategies outlined above with them.

- Symmetry

Three students (Carine, Adeline, Ludovic, Table 2, col. 3) related the symmetry argument to the judgment that the hypothesis led to incoherence (step 1b):

> ***Int.:*** Disregarding the basket for the moment, if you have the same pressure there and there, if everything is symmetrical, is there some reason why it would move in one direction or another?
>
> ***Ludovic:*** Well no. In order to make it move in one direction, you need the inner air to push harder than the outer air.

- Local explanation

The majority (n=8, Table 2) of the eleven students who had not been convinced by the symmetry argument ended up (step 1b of the interview) declaring that the suspect hypothesis was incoherent, in terms of the local and mechanistic argument.

> ***Int.:*** Let's see what happens on a small part of the envelope. If the pressures are the same inside and outside, the forces of pressure are equal so…
>
> ***Céline:*** They'll cancel each other out.
>
> ***Int.:*** Yes, they are the same on both sides, OK? Everywhere on the envelope, you repeat the same thing, so what happens to the entire envelope if they cancel each other out?
>
> ***Céline:*** Well it… Ah yes… But you told me it wasn't a party balloon… Well, it doesn't move… I don't know… It doesn't move, does it?
>
> ***Int.:*** There we are. If they cancel each other out, there's no overall force applied to it. So isn't what he says a little strange? And don't forget the basket below, and its weight.
>
> ***Céline:*** Yeah, on top of that! It's not normal. I agree. So he's saying something strange here.

So, it appears that, for these students, the local mechanistic argument is more effective than reasoning in terms of symmetry. But it is worth noting that, with one exception (Céline), they did not adopt an unambiguously critical attitude at this stage; they seemed to be unsettled rather than ready to think for themselves.

The other three (Emmanuelle, Laura and Thomas) did not reach a satisfactory understanding at that point, for different reasons.

Seeing the problem once Archimedes' principle was better understood

Two of these students (Emmanuelle and Laura) became aware of the incoherence in the paper at the moment of the explanation of Archimedes' upthrust (step 1c). They had a strong reaction when they understood the source of the upthrust, that is to say the pressure gradient. And they straightforwardly linked it to the problem in the simulated article.

> ***Int.:*** And finally, if you add them up, you'll have forces at the bottom of the cube that will be greater than at the top.
>
> ***Emmanuelle:*** OK, and that's what lifts it up.
>
> ***Int.:*** Yes, that makes the resulting upward force. That's Archimedes' upthrust. It comes from the pressure gradient acting on a body.
>
> ***Emmanuelle:*** OK. So here [at the top of the balloon] the pressures can't be the same, otherwise it wouldn't make the balloon move, would it?

By casting new light on the faulty hypothesis, this explanation of Archimedes' principle even caused a second strong reaction in two other students who had seen the incoherence earlier (Table 2, col. 5):

> ***- Nuno:*** There *(in the article)*, he means that the pressure is the same… So there's something wrong here! He's only talking about the temperature and the pressures would be the same… But in that case, Archimedes' upthrust wouldn't apply, would it?
>
> ***- Laurence:*** So in that case, there's no pressure gradient according to what he's saying, so you have no idea where his upthrust comes from!

Reacting to the incoherence after the two graphs were explained

Eleven students (Table 2, col. 6) reacted strongly at the end of the quite complex explanation of the principle of the hot air balloon (as in figure 1; step 1d), as they realized how misleading the criticized hypothesis was:

> ***Int.:*** So at the top of the balloon…
>
> ***Carine:*** You have the inner pressure that's greater than the outer.
>
> ***Int.:*** Exactly.
>
> ***Carine:*** That makes it rise. That's not at all what it says here! *(She is showing the article.)*
>
> ***Int.:*** No, that's not really explained in the article.
>
> ***Carine:*** Oh no! Because honestly, when I read it, I didn't understand it this way. The fact that he says that the density depends on the pressure and the temperature… To me, it really was at a constant pressure all the time and by making the temperature vary… But in fact, the temperature makes the pressure vary too. That's what isn't explained.

Clues indicating a clearly critical attitude

As shown in Table 2 by the letter A, all the students, by the end of step 1e, had become aware that the suspect hypothesis was incompatible with a consistent explanation of the phenomenon. Ten of them had reacted strongly concerning its validity on more than one occasion.

Table 2. Steps in students' intellectual paths: Awareness of the incoherence and critical attitude.

Name and "scientific origin"	From the start	First oral question about the hypothesis	Argument of symmetry Step 1b	Local explanation Step 1b	Origin of Archimedes' upthrust and link with the pressure gradient Step 1c	Plotting of the graph Steps 1d and 1e	When asked if they felt able to explain Step 2
Nuno (β)	C_0	A / C		A	A	A	
Ludovic (β)	C_0	A	A			A	C
Laurence (β)	C_0	A		A	A / C	A	
Carine (β)			A			A / C	
Adeline (φ)			A			A / C	
Céline (β)				A / C			
Côme (ι)				A			C
Damien (β)				A			C
Dima (β)				A		A / C	
Anna (μ)				A		A / C	
Marion (φ)	C_0			A		A	C
Emmanuelle (α)	C_0				A	A / C	
Laura (φ)					A	A	C
Thomas (φ)						A	C

'A' indicates when the students clearly showed their awareness of the incoherence.
'C_0' indicates some signs of a critical attitude from the start, not yet focused on the hypothesis (cf. Table 1, col. 4).
'C' indicates when the students first used their awareness of the incoherence to criticize the article or to retrospectively criticize their own attitude during the interview.

By the end of the interview at least, all the students, at different stages, had finally reached a critical attitude, which we indicate with the letter C in Table 2. What we mean by a 'critical attitude' is that the students had acquired enough distance to criticize the article as such and/or their own previous attitude.

For example, five students (Côme, Laura, Carine, Adeline and Ludovic) ventured to find fault with the way the author had written the article, beyond their criticism of the problematic hypothesis alone:

> ***- Ludovic:*** By simplifying things, you deform reality.
>
> ***- Adeline:*** That's true; he doesn't explain all the links between pressure, density, temperature and so on…

Table 2 also shows that, for most (8/9) of the students who had not initially given any sign of a critical stance (see Table 1: Côme, Laura, Carine, Damien, Dima, Anna, Thomas, Adeline), there was a time lag between their first awareness of a problem with the faulty hypothesis and the moment when they reached a clear critical attitude towards the proposed text. Five of them even overtly regretted having read the text too quickly or carelessly (see Table 1, col. 4):

> ***Int.:*** Do you understand? Do you have any questions?
>
> ***Anna:*** Well, it's true that when you read that (*she shows the article*), you swallow it

without asking yourself any questions about the physical reality.

Three other students (Nuno, Laurence and Marion, Table 1, col. 4) – although we found that they had already adopted a rather active intellectual attitude from the beginning of the interview – showed great regret at their initial lack of attention, at the end of the interview:

Int.: Do you have any questions?

Laurence: Well, I have questions about the article! Where does this sentence come from? Because when I read it, I didn't see any problem!

c. A posteriori attitudes and desire to reinvest the process

Analysing the comments collected during the final stages of the interview (3a, 3b and 3c), we focused on various aspects that were likely to be linked, more or less directly, to the students' desire to reinvest the process they had just participated in, in their future profession; these are:

- the level of self-confidence they had reached (relating to *RQ2*);
- their personal estimation of the value of the approach adopted (relating to *RQ2*);
- the extent to which the cost in time was seen as worth the trouble (relating to *RQ2*);
- their expectations about what they would try to do in this respect in their future professional activity (relating to *RQ1*).

Our observations are as follows:

Self-confidence

Before the end of the interview (steps 2a, 2b), all the students felt they were able to explain the phenomenon under study to somebody else, the way we had just done:

Int.: Do you think you could explain it to somebody else yourself?

***Côme*:** Well… Yes, it's feasible. I can explain it. Maybe not in a simple way but I could explain it, I think.

Of course, this does not mean that they would actually be able to provide a satisfactory explanation. We just observed their feeling in this respect, keeping in mind that no institutional reward – such as a good mark – depended on their answer.

Intellectual satisfaction

In step 3a, all the students interviewed, except one, said they had derived intellectual pleasure from the subtle reasoning proposed. Their ratings (all but one gave 3 or 4, on a scale of 1 to 4: see Table 1, col. 5) attest to their satisfaction, which is confirmed by explicit statements:

Côme: Ah yes! I always like understanding things! You've just made me a happy man! I like it!

Some students even specified where their feeling of pleasure came from: being aware of their modest command of physics, they felt all the more satisfied at having overcome all the difficulties and finally having understood this demanding explanation.

Laurence: Yes. I'd say 3. As it began with something that wasn't obvious to me, it's all the more pleasant to discover things with someone else and by participating. The satisfaction is even greater because of all the difficulties you succeed in overcoming.

Recognition of the value of the time and effort spent on the subject

In Step 3b, the students were asked if it was worthwhile understanding the principle of the hot air balloon in the way we had explained it and spending some time getting to do so. Their ratings on this aspect (Table 1, col. 6: all but one 3 or 4 on a scale of 1-4) indicate that thirteen students seemed to accept the time spent on the problem willingly. For example, Nuno, whose first rating was 3 on the principle that he never gives the maximum mark for anything, finally gave a 4 rating because he found spending this time on such a discussion so interesting:

- Nuno: I even think that… It's not only useful, it's also… I've understood, I've reasoned,

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I've made my little graph in order to understand all this reasoning, with this formula you explained to me, so yes! According to me it's even compulsory!

Int.: What rating would you give?

Nuno: I would say 4. The more you learn, the better it is.

Int.: Ah! You give a 4 now?!

Nuno: Well… Let's say 3… It's difficult to choose a mark between 3 and 4! Let's say 3.5! Because we needn't overdo it! But what you used here was indispensable.

- Marion: If going further in the explanation has got to take us through this, I think it's important.

Application to their future profession

In this part of the interview (step 3c), the students were asked to imagine that they were a scientific journalist who had to write an article on the functioning of the hot air balloon. The time the students spent on this question – no less than 10 minutes – shows how involved they felt in the discussion. All clearly stated that they were ready to re-use the analysis they had been shown for a popularization article (see col. 7 and 8 in Table 1).

Int.: Do you think it's worth using this explanation, if you ever had to write an article, even though it takes more time, even though it's more complicated?

Laurence: If it's worth it? That's an odd question! Yes, of course it's worth it!

Int.: You could have said this article was sufficient…

Laurence: Well, I'm not in a position to say 'no, it's useless!'

Int.: You could have said it was too complicated…

Laurence: No no! It's not complicated at all! Honestly, I'm really bad at physics, I base my argument on secondary school learning and it's not my thing! So, yes it's worth it!

However, they did not all agree on the way they would manage this. Some of them told us in detail how it would depend on several factors, such as the length of the article, the readership, the kind of publication and so on. Their responses referred in particular to one thing they judged indispensable: the adaptation of an article, as regards both form and substance, to the different kinds of readers. Clearly, this tallies with a major concern in their training, one considered crucial in the community practising scientific journalism. They weighed the constraints and all expressed their desire to take up such a challenge.

- Readership

As indicated in column 7, Table 1, thirteen students thought that this demanding approach was easily accessible to people who are not particularly specialized in physics, such as the 'general public' (n=5), or pupils from 'lower secondary school' (n=7) or 'higher secondary school' (n=1).

Céline: […] It depends on the way it's done but I think it's accessible to anybody. […] Of course! Because it's physics and you learn that in lower secondary school.

For one student only, this approach should be limited to specialized publications, intended for scientifically literate people.

- Formalism

Eight students (col. 8 in Table 1) were in favour of a degree of formalism (lower or higher secondary school level). Since they considered it necessary to their own comprehension, they thought it would help readers follow the reasoning. Despite the clues pointing to their initial unfamiliarity with the formalism (for 6 of them), and in contrast to their first reactions, they expressed their intention to include the proposed formalism in an article, and their judgments at the end of the interview were very optimistic:

> ***Int.:*** To what kind of readership do you feel able to explain this?
>
> ***Laurence:*** To teenagers. Because I think you start to learn that kind of thing in secondary school and it would be too bad if I couldn't use any formulae. I would have a lot of trouble explaining it to younger people, I think.

Others judged that it was possible to use this kind of approach without integrating any formalism, considering that a formal approach would discourage any reader. For example, Emmanuelle was frankly opposed to using a formula or a graph in an article:

> ***Int.:*** You think that a graph, a formula…
>
> ***Emmanuelle:*** They should be ruled out.
>
> ***Int.:*** They should be ruled out of an article?
>
> ***Emmanuelle:*** Yes, I think there are two diagrams that can be used: this one *(she shows the diagram in the article)* and that one *(the cube in a basin of water to explain Archimedes' upthrust)* but the formula and the graph, you must get rid of those straightaway, because in addition, you see, you would have to explain the graph. […] Well… There are too many things to explain, I think.

Discussion of the results

Our results cast light on our two research questions as follows.

The first question (*RQ1*) was whether student journalists and science mediators could take a positive view of the prospect of promoting the coherence of physics in their future professional activity. Clearly, this question can be answered in the affirmative, after this particular interaction with the experimenter. Thus Table 1 shows that all fourteen interviewees declared that they would willingly write a popularization paper with the type of demanding analysis they had just been presented with. When asked about the readership (Table 1, col 7) and the style of such a paper (with or without formulae or graphs: Table 1, col. 8), their answers were less uniform. But only two of them restricted the appropriate readership to "scientifically literate" people or "higher secondary school" pupils. The others envisaged "general public" (5) or "lower secondary school" (7) readers, and more than half (8/12) even envisaged the use of formulae and graphs. Experienced journalists might find such answers lacking in realism, but here we consider them as an experimental result relating to our research question (*RQ1*): The interviewees were open to the idea of fostering coherence in their future practice, albeit at the expense of what was considered realistic in their future professional environment.

In fact, as said above, the informative value of such results has to be related to the potential obstacles that the interviewees may have had to overcome. We had expected their levels of specialization in physics to be low (*po1*). Table 1 (col. 2) clearly indicates that this was the case. Also, a tendency to consider the written word with deference was to be expected (*po2*), and was actually observed (Table 1, col. 3). It is worth noting, in relation to their future readers' receptiveness concerning coherence (*po3*), that we have very little basis on which to estimate their *a priori* views: our experimental design consisted in introducing the discussion with a particular example in physics *before* attempting to document their positions in this respect. The complexity of the chosen topic was, we thought, sufficient to maximize the risk of rejection on the basis of excessive difficulty.

So, given what was observed in the interviewees at the beginning of their interaction with the experimenter, and given the complexity of the topic broached, we suggest that the students' final attitude was by no means obviously to be expected. This is a result that cannot be evaluated without considering the difficulty of the physical analysis discussed.

Our second research question (*RQ2*) sprang from the hypothesis that it was unlikely that students would plan to foster coherence in their future jobs if they themselves had not derived any personal satisfaction from this exercise. Our question was: to what extent had they derived satisfaction from the rigorous analysis they had just been presented with? Table 1 (col. 4) shows that all but one rated this aspect 3 or 4 on a scale from 1 (low) to 4 (very high), which provides an unambiguous answer to our research question. When asked to consider the time cost for this outcome, again all but one rated the value of the interview - despite the time it took - 3 or 4 on a scale from 1 (low) to 4 (very

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high) (Table 1, col. 5). Moreover, the content of the students' comments, extensively reported in this paper, is very explicit about the source of their satisfaction. What they say can hardly be reduced to a feeling of happiness at having been considered individually. In particular, they explicitly mention the value of going beyond a superficial reading, and even of confronting some real difficulties.

Another group of results, summarized in Table 2, concerns the individual progression of each interviewee. When first presented with the problematic hypothesis, not one of them detected the problem, which is in line with our previous results with physics students. But during the interview, they offered a more nuanced view. With the interviewer's guidance they attained a strong conviction that the hypothesis was not valid, doing so at different stages of the interaction with the experimenter. When presented with an alternative explanation, on the basis of two linear dependencies of pressure versus altitude, they eventually found the alternative satisfying.

It is striking that seeing the problem did not always prompt an immediate change of attitude among those who had initially been rather passive in their reading. By the end we observed, in nearly all the students, an actively critical attitude, in particular their readiness to think for themselves, without desperately searching through memories of school learning to corroborate the article. But, with half of them, this happened only after a time, i.e. once the alternative explanation was well understood. Before that, they had been unsettled, and had needed to comprehend the topic fully to allow themselves to express a criticism. This result may not seem very surprising. But what is to be noted here, in contrast to their slow start, is the students' unambiguous reactions at the end of the interview.

This result was not obtained by chance. We had planned strategies – or counter-arguments – to make the students aware of the problem with the faulty hypothesis. Between those strategies, there was a general preference for the mechanistic counter-argument over the argument appealing to symmetry. The individual intellectual progressions showed interpersonal variability and, frequently, a need for more than one reason before abandoning a misleading idea. Such an endeavour clearly necessitates detailed preparation on the interviewer's part.

This said, the limitations of this study must be borne in mind. One is the small number of students consulted. Thus it would be useful to conduct a replication. Also, it would probably be preferable to work with populations having a more homogeneous background, given that, in our sample, we had students whose last diplomas were from different fields. One remark can, however, put this limitation in perspective: the three interviewees who showed the most potential competence in physics were from archaeology, biology and physics respectively, which suggests that the last diploma – alone – is not a strong indicator of conceptual competence in physics.

The format that we chose for the interaction with the students consulted – that of an individual 'teaching experiment' (Komorek & Duit, 2004) – may be seen as another limiting aspect. It might be suggested that such a format, *per se*, can explain the satisfaction expressed by students. However, as argued above, it is unlikely that this factor alone could account for our results. It is worth noting, in this respect, that our previous results using the same experimental design with physics students do not show any marked difference between the comments collected with the individual and group formats respectively (Viennot, 2005, 2006; Mathé, 2006). It may be also thought that this format is somewhat stressful, which might reinforce the students' initial tendency to extract sentences directly from the text, in order to keep the conversation flowing. Therefore, it might be useful to assess the impact of this aspect, and to conduct an investigation with a more collective version of our experimental design, while taking into account our results concerning students' varied reactions.

This remark introduces an inbuilt limitation of this investigation. As said above, in adopting a teaching interview format, we do not claim that we have designed and evaluated a teaching sequence that we consider appropriate for the training of future science mediators and journalists. Here, this format has been used as an instrument to investigate students' reactions with respect to coherence. To this end, we chose to provide them with a personal experience of hard-earned understanding, in order to better assess their attitudes to the standpoint (1) that inspired this study.

Thus, we do not directly address the question of *how* to inject such a concern for coherence into a training programme, for a given audience of future mediators or journalists, at a given stage in their development. We are conscious that the purposes of science journalism are significantly different from those of science education, and that the stresses that shape training in each case are very different (e.g. Bauer 1992). In particular, the delicate and much discussed balance between rigour and attractiveness, or precision and communication, should obviously be a central topic of such a programme.

Our results do point to the usefulness of a detailed analysis of the topics covered and the students' intellectual paths, in order to avoid losing sight of relevant aspects of this debate. In particular, the time lag often observed between the moment when a student becomes aware of incoherence in a text and that when he or she feels free to criticize it explicitly is a parameter that should not be neglected. It is also significant that it is not always the same counter-example that can help a trainee to reconsider his/her position.

Should our standpoint (1) become an important component in the rationale chosen for a whole training programme, some innovative teaching-learning sequences should first be designed in detail and evaluated accordingly. Moreover, a decisive factor in such an endeavour is the role of the trainers. For this reason, experimentation should be conducted, ideally, with different teachers having different types of links with research (Leach & Scott, 2002; Millar, Leach, Osborne, & Radcliffe, 2006). In relation to such a research programme, our investigation is evidently very preliminary: our results simply provide some items of information about the students themselves.

Concluding remarks

The question that oriented this investigation was, put briefly: to what extent is it possible to foster in future science mediators a concern for showing the coherence of physics? It has been argued that this goal is valuable from two standpoints. First, a search for coherence, a term that refers here to the high degree of internal consistency and predictive power of physical theories, is intrinsic to physics; therefore, science mediators should not give distorted ideas of this science. Second, these aspects of physical analysis might act as levers, in terms of intellectual satisfaction, for readers of popularization papers. According to this logic, future mediators should themselves have been given access to this kind of experience, if they are themselves to act as promoters of these ideas. On the other hand, it may seem *a priori* difficult to pursue a twofold goal of this kind, given that future mediators' levels of expertise in science are generally not very high, and that the same can be said of their future readers.

Our results, recapitulated and discussed in the preceding section, appear positive in terms of journalists' and science mediators' reactions just after an intervention designed to prompt demanding search for coherence and, thereby, intellectual satisfaction. As to their intentions for their future profession, what they said immediately after the interview supports the following hypothesis to a large extent. Having experienced what they considered a satisfying interaction, students readily expressed a will to promote such a feeling among their future audience themselves. Of course, we do not consider this fact to be highly predictive of their future practice, given all the constraints they will meet. We only see this reaction as a clue that our experimental design found a positive echo in the students consulted. This finding supports the case for the purpose of fostering students' concern for coherence, a purpose to be considered among, and in a trade-off with, other major goals of journalists' and science mediators' training.

These results also suggest that this type of investigation can hardly be conducted without a detailed examination of the topics broached and the intellectual paths followed by the students.

Our findings may appear limited, given the range of investigations that remain to be done in this field. To our knowledge, research in journalism education has not reached a degree of development comparable to that observed in formal science education. It might be useful, in particular, to document views commonly held by trainers and to examine, correspondingly, the experimental results actually available in this domain.

More widely, i.e. including formal science education as well, there have been very few studies to date examining emotions linked to a cognitive evolution, derived from a particular teaching-learning process, on specific conceptual themes, and envisaged as possible outcomes of this process rather than as preconditions for learning. We suggest that research into students' motivations with respect to science might further develop this fine-grained approach.

References

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: A critical review of the literature. *International Journal of Science Education,* 22(7), 665-701.

Bandura, A. (2001). Social cognitive theory: An agentive perspective. *Annual Review of Psychology,* 52, 1-26.

Bauer, H. H. (1992). *Scientific Literacy and the Myth of the Scientific Method*. Urbana: University of Illinois Press.

Bradamante, F., & Viennot, L. (2007). Mapping gravitational and magnetic fields with children 9-11: relevancy, difficulties and prospects. *International Journal of Science Education*, 29(3), 349-372.

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of a girl does science? The construction of school science identities. *Journal of Research in Science Teaching,* 37(5), 441-458.

Cassady, J. C., & Johnson, R. E. (2002). Cognitive test anxiety and academic performance. *Contemporary Educational Psychology,* 27, 270-295.

Cavallo, A. M. L., Rozmann, M., Blinkenstaff, J., & Walker, N. (2003). Students' learning approaches, reasoning abilities, motivational goals, and epistemological beliefs in differing colleges science courses. *Journal of College Science Teaching,* 33, 18-23.

Clough, M. P. (2007). Teaching the nature of science to secondary and post-secondary students: Questions rather than tenets. The Pantaneto Forum, Issue 27, January, from http://www.pantaneto.co.uk/issue25/clough.htm

Clough, M. P., & Olson, J. K. (2007). Teaching and assessing the nature of science: An introduction*. Science & Education,* 17(2-3), 143-145.

Dimopoulos, K., & Koulaidis, V. (2003). Science and technology education for citizenship: the potential role of the press. *Science Education,* 87(2), 241-256.

Driver, R. (1989). The construction of scientific knowledge in school classrooms. In. R. Miller (Ed.), *Doing science: Images of science in science education* (pp. 83-106). New York: Falmer Press.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science.* Buckingham: Open University Press.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education,* 13, 105-122.

Giancoli, D. C. (2005). *Physics* (6th ed.). Instructor Resource Center, CD ROM, Prentice Hall.

Glynn, S. M., Taasoobshirazi, G., & Brickman, P. (2007). Nonscience majors learning science: A theoretical model of motivation. *Journal of Research in Science Teaching,* 44(8), 1088–1107.

Jenkins, E. W. (1997). Towards a functional public understanding of science. In R. Levinson, & J. Thomas (Ed.), *Science Today* (pp. 119-136). London: Routledge.

Jenkins, E. W. (1999). School science, citizenship and the public understanding of science. *International Journal of Science Education,* 21(7), 703-710.

Jiménez-Aleixandre, M. P., Agraso, M. F., & Eirexas, F. (2004). Scientific authority and empirical data in argument warrants about the *Prestige* Oil Spill. *Annual Meeting of the National Association for Research in Science Teaching*, San Diego.

Jiménez-Aleixandre, M. P., & Pereiro-Munoz, C. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education,* 24(11), 1171-1190.

Jiménez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). 'Doing the lesson' or 'doing science': Argument in high school genetics. *Science Education,* 84, 757-792.

Jurdant, B. (1975, February). La vulgarisation scientifique. *La Recherche,* 53, 141-160.

Keith, T. Z. (1993). Causal influences on school learning. In. H. J. Walberg (Ed.), *Analytic methods for educational productivity* (pp. 21–47). Greenwich, CT: JAI Press.

Kolstø, S. D. (2001a). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socio-scientific issues. *Science Education,* 85(3), 291-310.

Kolstø, S. D. (2001b). 'To trust or not to trust…' - pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education,* 23(9), 877-901.

Komorek, M., & Duit, R. (2004). The teaching experiment as a powerful method to develop and evaluate teaching and learning sequences in the domain of non-linear systems. *International Journal of Science Education,* 26(5), 619-633.

Korpan, C. A., Bisanz, G. L., & Bizanz, J. (1997). Assessing literacy in science: Evaluation of scientific news briefs. *Science Education,* 81, 515-532.

Koulaidis, V., & Ogborn, J. (1995). Science teachers' philosophical assumptions: How well do we understand them? *International Journal of Science Education,* 17(3), 273-283.

Kuhn, D. (1991). *The Skills of Argument*. Cambridge: University Press.

Laukenmann, M., Bleicher, M., Fuβ, S., Gläser-Zikuda, M., Mayring, P. & Rhöneck, C. V. (2003). An investigation of the influence of emotional factors on learning in physics instruction. *International Journal of Science Education,* 25(4), 489-507.

Leach, J., & Scott, P. (2002). Designing and evaluating science teaching sequences: An approach drawing upon the concept of learning demand and a social constructivist perspective. *Studies in Science Education,* 38, 115-142.

López Rodríguez., R., & Jiménez-Aleixandre, M. P. (2007). ¿Podemos cazar ranas? Calidad de los argumentos de alumnado de primaria y desempeño cognitivo en el estudio de una charca. *Enseñanza de las Ciencias,* 25(3), 309-324.

Márquez, C., Prat, A., & Marbà, A. (2007). A critical reading of press advertisement in the science class. *Paper presented (and handed out) at the meeting of ESERA 2007*, Malmö (21-25 August), abstract p. 215.

Mathé, S. (2006). *L'esprit critique d'étudiants peu spécialisés en physique, avant et après mise en alerte*. Master's thesis, Didactique des disciplines, Université Paris Diderot – Paris 7, LDSP.

Maury, J. P. (1987). *L'atmosphère*. Paris, Palais de la Découverte : Hachette.

Mazzitelli, C. A., Maturano, C. I., & Macias, A. (2007). Estrategias de monitoreo de la comprensión en la lectura de textos de ciencias con dificultades. *Enseñanza de las Ciencias,* 25(2), 217-228.

McIlwaine, S. (2007). Journalists and journalism education must grasp the democratic science opportunity. *The Pantaneto Forum*, Issue 26, April, from www.pantaneto.co.uk/issue26/mcilwaine.htm

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning of different grade, ability, and knowledge levels. *Cognition and Instruction,* 14(2), 139-178.

Meyer, P. (1991). *The new Precision Journalism*. Bloomington: Indiana University Press.

Millar, R. (2005). Scientific literacy: A feasible goal? In. V. Tselfes, P. Kariotoglou, & M. Patsadakis (Ed.), *Science: Teaching and learning in the context of compulsory education. Proceedings of the 4th Greek-national conference on science education* (pp. 18-26). Department of Early Childhood Education, University of Athens.

Millar, R., & Driver, R. (1987). Beyond process. *Science Education,* 14, 33-62.

Millar, R., Leach, J., Osborne, J., & Radcliffe, M. (2006). Research and practice in education. In. R. Millar, J. Leach, J. Osborne, & M. Radcliffe (Ed.), *Improving subject teaching* (pp. 3-23). London: Routledge.

Norris, S. P., & Phillips, L.M. (1994). Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching,* 31, 947-967.

Novak, J. D. (1977). *A theory of education*. Ithaca, NY: Cornell University Press.

Ogborn, J. (1997). Constructivist metaphors of learning science. *Science and Education,* 6*,* 121-133.

Ogborn, J. (2008). Science and commonsense? In E. Sassi & M. Vicentini (Ed.), *Connecting research in physics education with teacher education*. International Commission of Physics Education. http://web.phys.ksu.edu/icpe/Publications/index.html

Pajares, F. & Schunk, D. H. (2001). Self beliefs and school success: Self efficacy, self concept, and school achievement. In R. Riding & S. Rayner (Ed.), *Self perception* (pp. 239-266). London: Ablex Publishing.

Perkins, D. N., Farady, N., & Bushey, N. (1991). Everyday reasoning and the roots of intelligence. In. J. F. Voss, D. N. Perkins, & J. W. Segal (Ed.), *Informal Reasoning and Education* (pp. 83-105). Hillsdale, NJ: Erlbaum.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research,* 63(2), 167-199.

Phillips, L. M., & Norris, S. P. (1999). Interpreting popular reports of science: what happens when the reader's world meets the world on paper? *International Journal of Science Education*, 21(3), 317-327.

Radcliffe, M. (1999). Evaluation of abilities in interpreting media reports of scientific research. *International Journal of Science Education*, 21(9), 1085-1099.

Rhöneck, C. V., Grob, K., Schnaitmann, G. W., & Völker, B. (1998). Learning in basic electricity: how do motivation, cognitive and classroom climate factors influence achievement in physics? *International Journal of Science Education,* 20(5), 551-565.

Sadler, T. D. (2004). Informal reasoning regarding socio-scientific issues: A critical review of research. *Journal of Research in Science Teaching*, 41(5), 513-536**.**

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socio-scientific issue. *International Journal of Science Education,* 26(4)*,* 387-409.

Sadler, T. D., & Donnelly, L. A. (2006). Socio-scientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education,* 28(12)*,* 1463-1488.

Shamos, M. H. (1995). *The Myth of Scientific Literacy*. New Brunswick, NJ: Rutgers University Press.

Simonneaux, L. (2001). Role-play or debate to promote students' argumentation and justification on an issue in animal transgenesis. *International Journal of Science Education,* 23(9), 903-928.

Thomas, G., & Durant, J. (1987). Why should we promote the public understanding of science? *Scientific Literacy Papers,* 1, 1-14.

Wellington, J. (1991). Newspaper, school science: friends or enemy? *International Journal of Science Education,* 13(4), 363-372.

Wellington, J. (1993). Using newspapers in science education. *School Science Review,* 74, 47-52.

Viennot, L. (2005). Teaching rituals and students' intellectual satisfaction: What can we do? In Word View on Physics Education in ICPE (International Conference Physics Education). University of New Delhi, (Miranda House, convener Pratibha Jolly), in press: London, World Scientific Publishing Co.

Viennot, L. (2006). Teaching rituals and students' intellectual satisfaction. *Physics Education,* 41, 400-408. Available: http://stacks.iop.org/0031-9120/41/400

Zimmerman, C., Bisanz, G. L., Bisanz, J., Klein, J. S., & Klein, P. (2001). Science at the supermarket: a comparison of what appears in the popular press, experts' advice to readers, and what students want to know. *Public Understanding of Science,* 10, 37-58.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching,* 39(1), 35-62.

Appendix: a simulated article proposed to students

A little physics...

The functioning of a hot air balloon

How does a big device like a hot air balloon manage to rise into the air? According to Archimedes' principle! We already knew how this works with bodies immersed in water. Well, it works in the same way in air, as in any other fluid. The hot air balloon, like any body immersed in air, undergoes a vertical upward force equal to the mass of the volume of fluid – the surrounding air – displaced.

For the balloon to rise, Archimedes' upthrust has to overcome two other forces which tend to pull it downwards: the weight of the air inside the envelope, and the weight of the basket and its contents.

On the day of takeoff, let us consider the latter weight to be fixed. As for Archimedes' upthrust, it depends on both the mass of the air displaced and the volume of the body immersed in this fluid – the volume of the balloon. But during the flight, these two parameters are also fixed.

So it is the weight of the air inside the envelope that can be changed and this is what can tip the balance. But how? By means of the burners placed at the inlet located below the opening of the envelope, which will heat this air. The density of a gas depends on the pressure and the temperature.

As for the pressure, it is the same inside and outside, because of the opening at the bottom of the envelope, through which the air can communicate. As for the temperature, warming the air make it less dense, therefore less heavy. From a certain temperature, in practice around 100° C, the weight of the air in the envelope will be low enough for Archimedes' upthrust to prevail over the weight of the basket plus that of the internal air. The balloon can then rise!

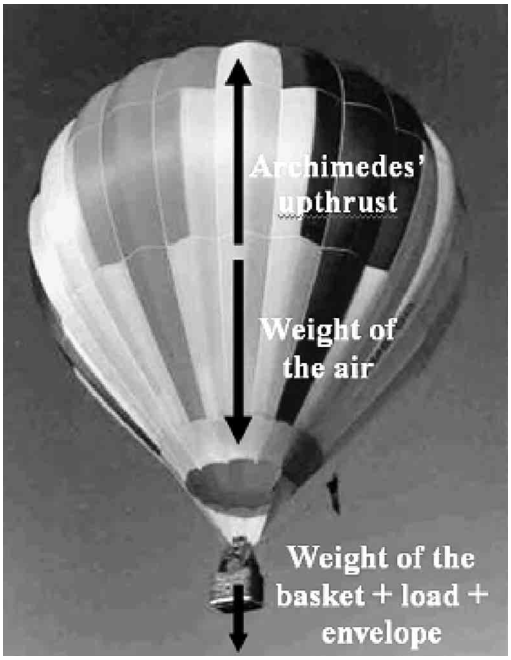

Figure 2. Forces exerted on a hot air balloon.

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