

PREFACE

Above all, Physics has got to be enthralling. That is what we all go on repeating, but here we are at the start of the third millennium faced with falling numbers, and the likelihood of a dearth of physicists in the near future. Many teachers will reply that in any case, as it is part of the curriculum, physics must be engaging. But the question remains, how can it be done?

This book is an attempt to find a partial response. Partial, but focusing on one particular aspect which is essential for a great many teachers. Others might not see things in the same way since, naturally, educational objectives come down fundamentally to a political choice. But choice entails knowing what's available and is realistically attainable. The important question here is that of the intellectual satisfaction of the learners.¹ The reader can judge for himself the importance of helping the students experience the pleasure of the thought process in physics; this is a point to which we will come back to in the conclusion. In the meantime, what concerns us is to propose elements which could help those teachers who wish to go deeper into this topic.

Of course, teachers count for a lot more than the official texts, despite strong influence of the latter and, as far as giving intellectual satisfaction is concerned, many will say that they haven't waited for official encouragement in order to pursue these high-minded ideals. But precisely, because there are so many constraints, it's important to be realistic, and a degree of humility is required. However, there is every hope that the resources used to achieve a given beneficial effect can be widely shared within the realistic contexts of education or scientific information.

To what extent is it possible to teach under realistic conditions while at the same time encouraging the intellectual satisfaction of our students? And how?

The purpose of the book is to cover this question, albeit, of course, within certain limits. We shall focus our attention on how the learner can acquire the power of

1 Several researchers have noted the expression "intellectual satisfaction" in their research. VIENNOT L. (2006) Teaching rituals and students' intellectual satisfaction, *Phys. Educ.* **41**, 400-408 (<http://stacks.iop.org/0031-9120/41/400>); FELLER I. (2008) *Usage scolaire de documents d'origine non scolaire en sciences physiques. Eléments pour un état des lieux et étude d'impact d'un accompagnement ciblé en classe de seconde*, Thesis, Université Paris Diderot (<http://tel.archives-ouvertes.fr/tel-00366318/>); FELLER I., COLIN P. & VIENNOT L. (2009) Critical analysis of popularisation documents in the physics classroom. An action-research in grade 10, *PEC*, **17** (17) 72-96; MATHÉ S. & VIENNOT L. (2009) Concern for coherence in journalists and science mediators-to-be: are they open to this prospect? *PEC*, **11** (11) 104-128.

reasoning in physics. We do not speak, as such, of “scientific procedure(s)”, or even somewhat more modestly of an “inquiry based approach”. Essentially, our interest here lies in the intelligibility and consistency of thought formulated by a student, an author, a supposed authority or any other participant. Intelligibility and consistency: how do we persuade teachers and students alike not to give up on these two areas? How can we measure the satisfaction of students seeing themselves grow intellectually and rewarded by persistence?

These questions seem to assign the (supposed) beneficiaries of this process to a relatively passive role, as mere recipients of the message. Are we perhaps going in completely the wrong direction at a time when so much value is placed on individual activity?

Well, yes, and no. What we want to emphasize here is the importance of acquisition of understanding, in the strongest, active sense of the words. Scientific training is not just training someone to make discoveries, still less training directly in making discoveries. The future citizen, even the future researcher, will need to grasp what others have said about science. How we react to the results of others or the positions they adopt is crucial. Not even the research worker spends all his time alone in research, far from it, in fact. He also has an eye on what others are doing (or he should be), and wonders what to make of their work. “Having the solution to a problem is not sufficient, you need to know how to make use of it”:² this maxim that we try to pass on to our students holds true in a much broader sense.

In invoking this ability, we refer to what is often known as the critical faculties. We are essentially interested here in one of its components: the pursuit of intelligibility, with the aim of assessing the consistency and field of application of the idea being analysed. This is therefore a somewhat restricted approach, since no attempt is made to examine issues such as the social relevance of the questions raised or the perceived image of the development of science in a given text.

However, neither is this a case of a process restricted to normally recommended practices (which most certainly have their use) of “checking the result” of a calculation via standard techniques such as dimensional analysis or even limiting cases.³

This book has a wider ambition, that of the intellectual satisfaction of our students gained through deeper understanding. In order to attain this, we rely on the great

2 VIENNOT L. (1997) *Corrigés modes d'emploi*, document LDAR (formerly LDSP), Université Paris Diderot, p. 2.

3 See below, Chapter 1, note 21. In this regard, it seems regrettable that this ability has been very little assessed in the French baccalauréat. See M. RIGAUT thesis (2005) *L'épreuve écrite de physique au baccalauréat : analyse du point de vue du contrat didactique, une étude centrée sur les années 1999 et 2000*, Université Paris 7 (www.matthieurigaut.net/public/docs/these_didactique_matthieu_rigaut.pdf).

internal consistency and predictive power of the physical theories currently in use.⁴ The question is how to get students to be aware of this.

However, before waxing too lyrical about the virtues of intellectual satisfaction, it has to be acknowledged that anyone seeking to grasp explanatory reasoning will encounter the prefix “satis” in the word “satisfaction”: so what will “suffice” for gaining an understanding? OGBORN *et al.* (1996)⁵ rightly emphasise that reasoning in the physical sciences in terms of explanatory power is rather like the tip of the iceberg: underneath is a mass of implicit theory underpinning both the explanation provided and the question posed.⁶ The authors propose this analysis in relation to teachers’ explanations in class, though we note in passing that it applies also to so-called common-sense reasoning: in both cases, the argument relies on elements accepted without discussion (below the iceberg’s waterline), either because they were previously learnt in class (and already partly digested) or because self-evidently attributed to common knowledge (BACHELARD).⁷

Pursuing this analogy, it seems that an essential basis for the intellectual satisfaction of anyone seeking understanding is his own adaptability to the waterline of the iceberg with which he is confronted. We are all familiar with the insecurity created when this is not the case, and any self-respecting teacher will take pains to avoid such a situation. Incidentally, it so happens that certain feelings of security may well be inappropriate: we shall see cases where what rouses the student’s interest is the sudden realisation that something previously thought to be understood, actually hasn’t been. In particular, (always, in fact) we have to be content with only a certain comprehension of the concepts involved. “Satis”, sufficiently, where is this optimal waterline, enabling greater comprehension to emerge without too many pointless or risky explanations? Naturally, in this book there is no absolute answer, simply explorations around the accepted norm.

Of course, we also feel that the acquisition of a line of reasoning is not merely “sufficient” acceptance of each of the links in the chain of the argument. Contrary to this intellectual reductionism, it is possible to experience flashes of insight that are the result of an unspecified mixture of intuition and rationality. According to DE BROGLIE,⁸ “A theory that succeeds, at a single stroke, in achieving a vast synthe-

4 For example: NEWTON’s laws. On the subject of excessive relativism, see OGBORN J. (1997) *Constructivist metaphors of learning science*, Science & Education, 6, 121-133.

5 OGBORN J., KRESS G., MARTINS I. & MCGILLICUDDY K. (1996) *Explaining Science in the Classroom*, Buckingham: Open University Press, p. 13.

6 They illustrate this with the behaviour of lithium, sodium or potassium when a piece is thrown into water, and the explanation linked with the periodic table of the elements, or even comments in molecular terms on the changes of state in the water.

7 BACHELARD G. (2002) *The Formation of the Scientific Mind* (Translation Mary MCALLESTER-JONES), Manchester: Clynamen Press.

8 DE BROGLIE L. (1941) *Continu et discontinu en physique quantique*, Albin Michel, Paris, p. 87.

sis (...) undeniably appears to the theorist as a thing of beauty, and might persuade him that it does indeed encompass a good part of the truth.”

Can we not imagine that this kind of feeling may be encountered at all levels of the learning process, thus encouraging students to delve still further into intellectual inquiry?

While not going as far as DE BROGLIE’s “vast synthesis”, it is nevertheless often the case that intellectual pleasure is associated with stretching the possibilities of the thought process. Hence, the convergence of conclusions derived from thought processes taking different paths can be a cause for intellectual satisfaction. This is far removed from the idea that, in terms of pleasure, just a single explanation can suffice. Whether it’s one explanation for a vast field of phenomena, or several paths leading to a single conclusion,⁹ the intellectual pleasure can be immense, even though ultimately the explanation which seems most “economical” will be described as the most “beautiful”.¹⁰ A single demonstration is “sufficient” to convince us that a conclusion is valid, but in terms of pleasure, who can claim that any one explanation is enough?

With some justification, it has often been said that one learns better when well motivated, and that a prime motivating factor is the practical applications of science and the way it ties in with the technical and functional demands of society. Likewise, images, for example, of cosmology and nanoscale phenomena have the potential to stimulate and fire the imagination. In a somewhat different vein, the framework in which activities are carried out can be a galvanizing factor; for instance, one might mention the university projects or the *Travaux Personnels Encadrés* (supervised individual work) launched in France in the *classe de Première* (Year 12) in 1997. However, although the importance played by such factors in the desire to acquire or develop critical faculties cannot be denied, in the present discussion they have only secondary roles. For here indeed is the central question in this book: in accompanying a student on the road to reason, can we provide her/him with intellectual pleasure independent of the usual motivational factors? Surely, the effort, and indeed it is an effort, is at least worth a try?¹¹ The proposed paths will necessarily involve abstraction, but at a level that should always be accessible. The associated pleasure can be compared rather to a hike in the mountains (a sport anyone can do) than to sunbathing on the beach.

9 See the example of the hot-air balloon in Chapter 6.

10 R. FEYNMANN wrote *The character of physical laws* (1965): “But the most impressive fact is that gravity is simple (...). It is simple and therefore it is beautiful”.

11 The idea of intellectual effort is very often excluded from the definition of what scientific popularisation ought to be. “Popularisation boasts of offering science without pain”, if B. JURDANT (1975) is to be believed, *La vulgarisation scientifique, La Recherche*, **53**, 149.

Of course, the previous comments echo those that often recur in our official teaching texts, and in that sense, they may not seem terribly original. However, the whole question is one of shifting the focus of what we do in practice to make the most of this official encouragement. Are these exhortations pointless in the real world? We often hear it said that students do not have sufficient critical faculties and that teachers do not have the time to help them with this. For our part, we refuse to equate realism with fatalism. Even so, this book does not attempt to deal with all the practical methods for promoting the learning of physics, especially as far as experimentation is concerned. It is to be taken simply as an appeal for greater shared pleasure, seeing beyond some of our conventional teaching rituals.

The suggestions which follow are illustrated by examples of appropriate teaching practices, typically at the end of secondary level or at the start of university, but applicable in principle to other levels. The content of the associated physics is deliberately simple. Stumbling blocks related to common tendencies in thinking and the rigid nature of teaching practices are highlighted with the aim of opening up choices and enabling better-informed teaching decisions. In particular, the ingredients commonly employed to make physics more “attractive” are reconsidered, either in the form of rather surprising and unconventional experimental mini-demonstrations, or in texts taken from popular science.

Thus, the Part I of the book analyses and illustrates one or two components of a fruitful thought process in physics, and high on the list of tools and techniques mentioned are functional dependencies and associated graphs, whose illustration is deliberately restricted to a few simple cases with additional practical suggestions. The Part II builds on the benefits of addressing different phenomena within the same formal approach, and different approaches used to analyse the same situation. The Part III puts into perspective the relative merits of experiments conducted along the lines of “mini-demos”, when they are so amazing that they dazzle the critical faculties. Normal use is completed with an in-depth reflection which, in particular, takes account of some tendencies commonly seen among teachers. The topics covered then finally merge with popularisation.

In the conclusion we return once more to the idea that, both as teachers and popularisers, there are more choices available to us than might appear to be so at first sight, and hence that our responsibilities must be taken all the more seriously.

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Thinking in Physics

The pleasure of reasoning and understanding

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