Teaching Introductory Physics
Arnold B Arons[1]
New York: John Wiley & Sons 1997
775 pp ISBN 0-471-13707-3 hbk

The book is difficult to review due to its enormous richness of content, opinions and penetrating *'story lines'* that command attention. It is very much a report of the lifetime's work of a pioneer in didactical physics. Its ideas are based on a life-long experience and supported by indisputable evidence from systematic research. I found it a source of great delight as well as of some irritation. And, I am sure, many readers will share both of these impressions, but with largely varying weights - and many will be irritated by what gives me most delight.

The book consists of three parts. Part I, *A Guide to Teaching for Learning and Understanding* (410 pp), contains the essence of the author's weighty message. The two others, Part II, *Homework and Test Questions* (212 pp) and Part III, *Introduction to the Classical Conservation Laws* (153 pp), are rather like extended appendices.

The author makes very clear the irreconcilable conflict between guidance-of-processes and delivery-of-products teaching. The guiding ideas of the former are introduced both in principle and in practical detail, and its promises and successes are compared with the damages caused by the latter.

Our teaching of physics is governed by a long-established tradition of *'backwards science'*, where physics is presented as a collection of end products, formulae, well-formulated definitions, canonical statements about atoms and electrons, quarks, gluons, big bangs, black holes and other *'esoteric vocabularies of modern physics'*.

We wish to present our students with the best treasures of science. Thus, we compete in lucidity of presentation. We compose detailed instructions for straightforward solution of end-of-chapter problems and for easy arrival at correct results in the laboratory exercises. We do our best to equip our students with correct answers, to save them from the trouble of thinking, and to ensure examination success.

The author asserts that *'dreams of accelerated learning'* are rudely shattered by the *'unwelcome truth'* of *'pathetically thin results'*. We are merely *'cultivating blind memorization without comprehension'* and are *'crushing our students into the flatness of equation-grinding automats'. 'We do not even give them a chance to begin to understand what "understanding" means.'*

As a result *'a great majority of university students of science and technology have no more understanding of the ideas involved than the seven-year-old ...'* They are *'not reasoning either arithmetically or algebraically but are simply arranging the symbols, in patterns that have become familiar.* They are *'unable to discriminate, what of knowledge they possess is based on evidence and understanding, and what consists of memorized, unsupported assertions'. 'This undermines their capacity to distinguish between jargon and knowledge.' 'This condition is destructive of any understanding of nature, power and limitations of science.'*

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[1] The text is identical with that published in Eur. J. Phys. 19 (1998) 316-318. A few footnotes are added to comment on editorial changes which have violated the original intention of the writer.

However, attempts to change the way of teaching meet strong resistance from all parties involved. The students are stubborn in their refusal to think for themselves and stick desperately to their right to learn by memorization. *'Teachers, insecure in the face of new materials, finding them "too difficult" for the children without being aware that the trouble really lies in their own lack of adequate understanding, band together and direct their energies and good intentions to writing materials of their own. The result is invariably trash that is full of errors ... '* The author refers to a *'destructive collusion between students and teachers*, in which they agree about the easy combination of non-teaching and non-learning through declaration and *'regurgitation'* of formulae and canonical semi-truths. *'By far the most difficult part of the problem is conveying comprehension of it to our ... colleagues, most of whom still operate on the premise that instruction ... can be effectively conducted by sufficiently lucid verbal inculcation and through the range of subject matter "coverage" that has become conventional.' 'The put-down was so forceful, and lack of interest in the audience so palpable, that ... '*

In spite of such strongly pessimistic overtones, Aron's treatment of his subject matter is most positive and stimulating. The text is linguistically rich and eloquent, often cleverly ambiguous, which makes the reading a delightful experience.

The basic principles of the processual approach are repeated and argued again and again to show their importance and meaning in different contexts. The students' preconceptions and misunderstandings, their reasons and remedies, as well as development of conceptual understanding, are analyzed in great depth and detail.

Introduction of concepts should follow the principle of *'idea first and name afterwards'*. *'Concepts are synthesized out of observational experience...'* They must be *'explicitly connected with immediate, visible, or kinesthetic experience.'* However, their meanings *'cannot be settled completely on the first encounter*.' *'Mastery develops slowly as the concept matures in the mind through use and application. 'Students should be made explicitly aware of the process of redefinition that goes on continually ...'*

Physics should start from *'realms of everyday experience rather than from esoteric vocabularies of modern physics.' 'Reasoning starts at concrete levels, provided that it is guided by a competent teacher, gradually proceeds toward the abstract.'*

'The opportunity to talk, argue, and explain in the course of observations and experiments contributes greatly to the learning. 'It is essential to *'engage the learner's mind in active use: 'How do we know? Why do we believe? 'It is important to distinguish between the observations that were made and the inferences drawn.* Students should be *'invited to predict what will happen, to argue about their predictions and to give their own verbal interpretation of their observations'* and should be guided *'through Socratic questioning in order to lead to articulation of operational statements.'* They should learn the significance of *'limiting the scope of inquiry to ensure winning of one step of understanding at a time ...''The students should get direct experience about how words acquire meaning through shared experience.'*

'The essential underlying role of linguistic elements and the importance of lingual matters' are also emphasized in several specific contexts like *'the development of the capacity for arithmetic reasoning*' and distinction of objects (body, particle) from their properties (mass, charge).

The importance of the history of science becomes most clear, not only as a source of interesting stories but as an essential guide to understanding the nature of concept formation and to appreciating its difficulty. There is also a strong call for *'infusion of liberal and humanistic perspectives'.*

All main areas of physics are covered, treated concept by concept and law by law, starting from the *'underpinnings'*, the very basic concepts of space, time, position, direction, size and shape. They are shown to be subject to an enormous generalization into modern ideas, to extend their significance also to the necessary mathematical representations, and to form, thus, the basis of all learning of physics.

Part I ends with a thorough analysis of what scientific literacy, understanding and critical thinking do and do not mean, and why one should bother with them. This is connected with a critical evaluation of policies and measures in the development of courses and curricula, with a discussion of possibly more successful strategies for the future.

I agree enthusiastically in both the detailed discussion of the conceptual development and the analysis of the principles involved. I admire the lucid break-down of the basic processual elements of learning and teaching for understanding, as well as the richness of detail showing the practical meaning and significance of these principles. I enjoyed several details of which I was not aware, like Ampère's argument[2] that the interaction of wires was not electrostatic in nature. I also share the anguish for the resistance encountered and for the obstinate repetition of the same errors.

The author's linguistic elegancy makes remarks, which indeed indicate the hopeless stupidity of the traditional approach, sound almost complimentary. My delight for this skill is strongly enhanced by the frustratingly unyielding resistance against my own parallel efforts. In a small country (Finland), where any American text-book is regarded as a superior authority for students and teachers, such statements as *'texts were obsolete, full of errors and mis-statements, and intellectually sterile being copied and recopied from each other for several generations by authors who themselves did not have adequate understanding of the subject matter'* are most welcome in all their critical frankness.

Part II of the book is a natural addition. It is a toolbox with a huge collection of problems and questions to support processual teaching. Even if just *'an invitation'*, it is an extensive, coherent and systematic collection It is also an excellent starting point to any ones own further development of ideas.

The author is wise enough to emphasize that he is not *'formulating prescriptions as to how items of subject matter should be presented ...'* While I eagerly agree with the main ideas and most of the contents, I also welcome the invitation to *'invent own terminology'*.

In the process of reading an uneasy feeling grew gradually, as if the author's compliance with the principles were not systematic and some unnecessary compromises with the *'backwards science'* were being made. Sometimes the meanings of concepts are extracted from formulae, in accordance with the traditional 'formula first, idea afterwards' (if ever), instead of creating them from observational perception. This impression was heightened by some passages in the discussion of

[2] MS said 'argumentation' referring to a set of empirical arguments and not just to one single argument.

work and energy, which I found somewhat sophisticated and formal.

Part III, finally, made me ponder about the nature of the large-scale conceptual structure of the book. This part seems to have the role of a closure of the great *'story-lines'*. But it seems to stem from an earlier period when the ideas were not yet ripe. Its approach to the classical conservation laws is clear and instructive. But it suffers from a heavy burden of traditional theory-based deductive argumentation with lots of formulae. It is interrupted now and then by beautiful discussions of scientific thought and concept formation as omens of the ideas of Part I.

The treatment of energy starts here with a long citation from Feynman's lectures praising the conservation of energy as an incomprehensible 'most abstract idea' and a 'mathematical principle' which can be approached only through calculation by formulae resulting in a number which 'does not tell the reasons ...'. A discussion of the widespread experience of energy in everyday life - which would normally be a starting point for exploring the concept[3] of energy from observational perception - comes as an 'idea afterwards'.

As another grand finale one finds a nice discussion of 'interactions' as they are perceived in nature. Similarly, or even more emphatically, I think, this would belong in Part I[4]. To me 'interaction' is the great underlying concept of whole physics. It was the great revolutionary idea of Newton, it grew into the core mechanism of all phenomena, and it is the key concept in frontier research today.

In this book 'interaction' is introduced in the context of an extended discussion of the problem of 'instant action' as leading to the development of the field concept. This is a jump into the middle of development of the concept, contrary to the principle of continual development of concepts. It is not given any role in the context from which it arises, the introduction of Newtonian dynamics. Instead, two possibilities of operational approaches are described, called Newtonian and Machian, starting from the quantification of force and mass, respectively. However, both of them seem to me pre-Newtonian in the sense that they deal only with the motion of one body. They do not make active use of the idea of interaction, which would require discussion of two bodies with one interaction as the starting point for perception of Newtonian meanings.

Thus, the traditional teaching problem of the third law remains unsolved. As stated by the author, it remains a *'part of the auxiliary text essential for full understanding'*. Similarly, the concept of momentum arises in the traditional way as a mystical afterthought. Its meaning as the necessary representation of changes of motion is hidden behind a long theoretical development. An active use of 'interaction' as the starting point would help in solving these problems and would lead also to slightly different views on the terminology related to energy and work.

Two minor related terminological notes can be added, both assuming importance because of fallacious lingual associations involved. *'Free-body diagrams'* are used, as in many books, in analysis of forces acting on single bodies of a system. 'Free' is, however, a term for bodies with no external interactions at all. In my experience, this has been a source of much confusion. I oppose also use of the established *'centripetal force'*. It is just a polemic term from Newton's time, now

[3] MS did not speak about 'exploring the concept but about 'creation of meanings' to emphasize the nonexistence of the concept in the start of the process.

[4] MS said here 'the beginning' referring to the beginning of the learning process or of the development of the concept and, not to the Part I. Thus, this editorial amendment obscures the idea of the sentence.

completely useless. Linguistically it refers to the body's own tendency, just as its counterpart, the *'centrifugal force.* In this sense 'centrifugal force' is much less problematic. It is a rather natural word for a common kinesthetic experience, which can be recognized as an inertial tendency of the body itself. Thus, force is not a proper physical term.

Finally, it should be emphasized that this is a most valuable book. It is in many ways an eye-opener which should be read carefully by all involved in practicing, planning or administrating physics teaching, on any level. It is an ample source of ideas and practical advice for development of physics instruction. With its covering set of thoughtfully collected set of references it will also become a stimulating invitation for many readers to research on didactical physics. It would, however, benefit from a more extensive index.

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