separata

012//

PLANNING AN INTRODUCTORY LABORATORY FOR PHYSICS FRESHMEN: TEN YEARS OF GROWING UNDERSTANDING AT SÃO PAULO UNIVERSITY

maiúsculas

L.B. Horodynski-Matsushigue
P.R. Pascholati
E.M. Yoshimura
M. Amaku,
R.M. de Castro
Z.O. Guimarães-Filho
E.W. Cybulska
N.H. Medina, J.H. Vuolo
Instituto de Física da Universidade de São Paulo
Caixa Postal 66318 CEP 05315-970 São Paulo SP Brazil

J.F. Dias
Instituto de Física da Univesidade Federal do Rio Grande do Sul
Caixa Postal 15051 CEP 91501-970 Porto Alegre RS Brazil

M.-L.Yoneama
Centro de Ciências Exatas e Tecnológicas (C6) da Universidade Vale do Rio dos Sinos
Av. Unisinos, 950 CEP 93022-000 São Leopoldo RS Brazil

lighia@if.usp.br

Abstract

Experience, and an overview of the literature, have shown that laboratory courses, particularly the introductory ones, should be planned taking into account previously chosen priorities, among possible aims. A group of teachers has been active for about ten years at the Institute of Physics of the University of São Paulo developing a course which puts emphasis on the aspects which characterize correct data aquisition and analysis, whatever the contents of the experimental problem. Weekly meetings of the teacher team (which occasionally changes some of its members and always includes some young physicists who are beginning their career), which last about two hours, are important means to foster the growing understanding of the process. It is now generally agreed that the goals should contemplate attitudes, as well as concepts. The attitudinal objectives intend at long term to induce the students to act more independently, autonomously and critically, albeit being cooperative and giving due value to team work. The conceptual objectives are centred around a better understanding of the statistical theory of experimental uncertainties and its relation to the data handling and analyzing processes. The planning includes four blocks, each with three to four experimental activities, along the two introductory semesters, the first of which is considered especially important as a beginning for scientific literacy. Students are responding increasingly well to the proposed approach. About two hundred and forty students enroll for Physics major at São Paulo and are divided into classes of about twenty, meeting four hours a week.

3053

I - Introduction

It is the aim of Science to interpret phenomena in as broad a context as feasible. Physics is concerned with most phenomena found in Nature and is considered an experimental science, from both, a historical point of view as well as from a philosophical one[Am98]. Therefore, it is distressing to see that in the vast majority of Physics programs, particularly at University level, experiments are presented to students in one of two equivalently inconvenient manners: either they are used as mere illustrations for physical concepts, already taught in the so-called *theoretical classes*, or they are thrown at the students without any sound sequence, apparently under the assumption that a variety of examples will result in an adequate synthesis of *what the experimental activities are about*, without further help.

In fact, the whole of Physics used to be taught up to the 40's or 50's of this century in this unstructured manner, and Biology, or parts of it, like Botany and Physiology, maintained this fragmented approach until much later. Nowadays it would be unthinkable to go back to the old text-books, full of isolated facts. Research in Education has clearly demonstrated that formation is much more important than information, especially at present, when facts can be stored on and conveniently recalled from small computers. Nevertheless, most Physics Labs in Brazil, and in other countries as well, are still a simple collection of *experiments*, which are vaguely related to topics which were *seen* somewhat earlier in *theory* classes. Frequently the outcomes of such methods are a mistrust of experimental results and a vague feeling of time being lost[To83], as was clearly recognized by W.C. Michels [Mi62], some time ago.

However, there is another complementary point of view. It is now admitted that there are several kinds of literacy, each with its specificity and difficulty. In present days, no one sends a child out to learn a language or math almost by himself, just by being exposed to several *stimulating* situations. The same should be true for scientific literacy and one should be able to analyze which are the cornerstones for promoting this specific competence. It is the view of the authors that one important point is to make the person recognize that Science is a human construct and, as such, fallible and always prone to modifications. Especially in this computer-based era, there is the need to see machines as something being *fed with programs* by humans. Therefore, it is essential that future Physics teachers, and also Physics majors, be early put into contact with this aspect of Science. Nowadays, Physics is mostly presented in *theory* classes as if it were a linear, already complete subject. At present, as Physics community, we are doing just the extreme opposite to what was usual up to the 40's. We must be aware of not doing so in the lab, allowing an inquiring spirit to persist.

Some of these ideas have, indeed, been expressed as early as 1951 [Ho51] and more consistently by J.C. Menzie in 1970 [Me70]. The way out of the dilemma, was tried through an *opening* of the laboratory activities, as in the *Divergent Laboratory* [Iv68] or through real project work, already in the undergraduate lab [Be71]. Most of these innovations did not survive.

II- Objectives and priorities

It is true that an immense variety of objectives and aims may be taken for the Physics Laboratory [Am98,Ho97,Ro79,Po84] and it is, first of all, necessary to choose priorities. Grossly speaking, the aims may be subdivided into conceptual and attitudinal ones[Ho97,Ca86]. It is important to maintain both kinds in evidence, since the smaller groups usually formed in lab activities may be a positive setting for interfering in favour of the latter, which is an opportunity almost lost in the overcrowded *theory* classes. On the other hand, teachers who are truly involved with introductory classes do not think they can transform their students rapidly into scientists, in the exact meaning of the word. It is often felt that an apprenticeship is needed, which should promote the necessary basic scientific literacy. Unfortunately, this understanding is almost never transformed into concrete proposals. The present report shows how evidences have led to action in São Paulo and resulted in an ever-changing program for the introductory Physics lab[Ho97,Ho99,Vu00]. The number of students which enroll to major in Physics at the University of São Paulo's central campus is about two hundred and forty and, in the lab, they are divided into classes of eighteen to twenty two students, which meet four hours each week.

About ten years ago, at the "Instituto de Física da Universidade de São Paulo" (IFUSP), it was decided[Va90] that, for Physics majors in Brazil, the first two semesters of what was called *Experimental Physics* should concentrate on the teaching of those aspects which characterize correct data taking and analysis, whatever the contents of the *experimental problem*. An important fact needs to be stressed in this context: it is impossible to appreciate the beauty of physical results without being able to understand and employ adequately the confidence intervals around the numerical values which result from measurements! To illustrate the particular Physics concepts, which were simultaneously taught at *theoretical classes*, experimental demonstrations in class were deemed more appropriate. Another way to accomplish that aim could be real-time computer-assisted experimentation, where certain control can be exerted on the outcomes and the analysis is mostly qualitative[Am98]. This is exactly one of the criticism the São Paulo team has to present about the recent report of the American Association of Physics Teachers-AAPT. There, the goals for teaching in the introductory Physics laboratory are classified in five broad aims, namely: I. "The Art of Experimentation", II. "Experimental and Analytical Skills", III. Conceptual Learning", IV. "Understanding the Basis of Knowledge in Physics" and V. "Developing Collaborative Learning Skills"[Am98]. It is strongly felt that it is impossible to attain success even with a single goal, if priorities within each of those broad aims are not established at the very beginning of the process, that is when an introductory laboratory is planned. No such hint is given in the AAPT report. Furthermore, an analysis has to be made as to which aims may be pursued in a less expensive way, in what refers to money and or time[To83], employing other instruments. Therefore, as stated, goal III of the aforementioned list is better supported by complementary investments to the *theory* classes. On the other hand, it is evident that goals I, II, IV e V can essentially be only satisfied if laboratory experiences are also provided for the students.

In the first couple of years, educational material for the two semesters was developed at IFUSP[Vu92,Vu96], focusing, in particular, on the correct statistical understanding and analysis of experimental uncertainties. Furthermore, the experiments assumed a more complex structure, even when dealing with the same themes as there had been formerly presented in the introductory laboratory[Vu92].

As an important aid in the teaching/learning process, each activity was divided into two four hour-periods of work with the teacher and the experimental material. In this way, an important pause for reflection was provided, before finishing analysis of the data collected, in the second period. Preliminary reports containing the experimental results and their analysis were elaborated by the students (in teams of two). These preliminary reports were handed back after being corrected, without being graded. This was meant to encourage team work and honesty, in accordance with views which are now prevalent [Am98]. Two different final so-called *complete* reports were used during the semester to assess each student's progress. The complete reports were written individually by the students, about themes randomly selected among all the ones explored during each of the two-months periods, utilizing the preliminary reports as basis. These methods are still in use [Ho00], but more recently, a written examination about analysis methods was also introduced, besides an elective final experiment, which occupies a prominent place in the process[Ho00].

III - More recent developments

In the last six years, a team of teachers, which occasionally changes by some of its members, has been working on establishing the cornerstones for significant experimental activity and devising means of attaining intermediate and, sometimes, final goals. All members are experimental physicists active in others fields of research, besides being interested in Physics Education, and there are always some very young physicists in the team, who are beginning their teaching career.

Although the structure initially designed for the course was meant to provide, to the majority of the students, a quick increase in maturity in what refers to conducting and analyzing experiments, it was soon perceived that some basic concepts were not absorbed, albeit much hard work. Some of the teachers who had a previous experience, also with students of other areas, were led to suspect that the meaning of experimental uncertainties is a rather difficult concept[Ho98,Ho99]. This has more recently been put forward also by other researchers [Jo94]. Along the years it is, in fact, being confirmed that the intrinsic statistical variability of outcomes of measuring processes is astonishing to most people, particularly to the beginners in experimental activities. On the other hand, no significant conclusion, which is based mostly on comparisons of experimental results with other information, can be reached without a clear quantitative idea of *how much* a result can be trusted. This is best accomplished through the statement of confidence intervals[Ho98], although the presentation of the correct number of significant figures could be sufficient. However, there is evidence that the concept of *significant figures* is still harder to convey.

In the planning of the teaching/learning process the São Paulo teacher team has put emphasis on the following conceptual objectives, taken sequentially: (*i*) to show that data normally fluctuate, if no instrumental limit (a device with insufficient precision) is introduced into the measuring process; (*ii*) to show that most significant histograms of collected data should be single peaked and with no obvious systematic tendency during acquisition; (*iii*) to convince the students that, in most situation, a gaussian curve is a reasonable representation for the histograms, defining the meaning of the standard deviation; (*iv*) to demonstrate that *more data* means more information and should result in narrower confidence intervals, expressing the meaning of the standard deviation of the mean; (*v*) to present the usual *propagation of uncertainties* as a convenient means of obtaining confidence intervals for secondary results, if the confidence intervals of the primary, independent, data are known; (*vi*) to put the students into contact with some easy ways to analyse relationships: linearization techniques and graphical analysis; (*vii*) to show the power of the analysis of residues and chi-square values, applied to the usual least-squares fits; (*viii*) to demonstrate that theoretical interpretations may present flaws, if the model is too restricted for the experimental situation.

At the same time some innovations were introduced which should produce positive effects on the attitudinal objectives, meant to help the students to be more independent, autonomous and critical individuals, which nevertheless are cooperative, scientifically honest and can give the due value to team work. The recent report of the AAPT [Am98] also values such objectives. The innovations tried at São Paulo refer to increasing team work and interdependence, which includes an ample sharing of experimental results. Also, attention is given to the amplitude and depth of the discussions about the outcomes of the experiments, important instruments for a better understanding of Physics. Furthermore, emphasis is always put on inserting the activities, even the first ones, in as broad a context as feasible, always trying to show that an question is being asked to Nature and that students and teacher employ the best of their efforts to understand her answer. This is in accord with the recent recommendations of the AAPT[Am98].

Synthesizing, the planning of the laboratory activities has grown up to touch several points of scientific literacy, which include conceptual and attitudinal aspects for which Experimental Physics can provide a nice and, sometimes the only, basis. In fact, there will always be some unsuspected outcomes to steer the discussion into a new path. To show that modelling of real phenomena can always be improved, taking then into account more and more of the less relevant variables, is one way we have explored to get the message through[Am97].

In practice, the activities planned to attain the mentioned conceptual and attitudinal objectives are divided into four blocks, each corresponding to about two months. The first of the blocks was conceived to demonstrate the variability of measurement results and to convince the students that the statistical approach to data analysis is robust. Four activities are included in the block, and histogramming of results taken in bigger (N = 50 to N = 100) and smaller samples (N ? 10), is extensively employed. Table I presents, in some detail, the conceptual and attitudinal goals which each of the experiments of the first block aims at.

Table I

Some conceptual and attitudinal goals for the experiments in the first of the four blocks.

Experiment	Conceptual Goals	Attitudinal Goals
Introduction to Measurements; timing of a pendulum by pairs of students with successively improved methods; comparison of small (N=10) and bigger (N=50) samples	Results fluctuate; histogramming helps; it is possible to determine a representative value and to estimate a characteristic width; these may be related to the mean value and twice the standard deviation	It does pay to be attentive and careful; to record data in an organized manner helps; it is necessary to learn to work in a team; measurements can be trusted; the experimentalist is part of the set-up

Relation between period and length of a pendulum; data for the length and the period of each of several similar pendulums are averages of measurements of 8-10 experimentalists which alternate among the pendulums; each one oscillating with a predetermined length and small amplitude	Physicists try to find the most relevant variables for each phenomenon and to obtain relations between them; taking bigger samples and making averages produces usually better results; doing graphs is worthwhile; linearization techniques help the analysis	It is important to be co-operative, to exchange and discuss information; mistakes can be found, if statistical concepts are applied; modelling phenomena means describing their most important aspects; better data need better models
Fractal objects; establishes the relation between mass and diameter of a series of crumpled paper balls[Go87];	Fluctuations in measurements have several sources, one of them may be irregularity of the proper object; Gaussians represent well most experimental results; standard deviations measure fluctuations; relations between physical quantities may be experimentally determined	Sampling must be careful and planned; given an experimental problem, one needs to choose adequate instruments; to interact with different people can be positive (students teams are changed)
Measurements and Statistics; dice are thrown in lots of n and the results recorded in samples of increasing size, N; background and source events are recorded with a Geiger-Müller detector in samples of increasing N	Statistical analysis works and should be applied to results of measurements; mean values are better determined as N increases, but the sample standard deviation remains the same [Ho98]	Use the experimental information and not expectations to support the conclusions: even in strongly controlled experiments, outcomes of small samples fluctuate; look at the outcomes with a critical eye

The first block is considered the most important one in the whole teaching/learning process of the introductory Physics lab and has undergone most of the changes during the last six years. In its present form, the synthesis of the statistical concepts [Ho98] is undertaken only in the fourth activity, when the necessary maturity seems to have been reached. In its previous, somewhat simpler version, ten years ago, a dice throwing activity was the first to be presented to the students and was felt by them as rather boring. As second activity, after an introduction to histogrammed measurement results, the effect of the synthesis through dice throwing was much better, but two years ago we decided to postpone it still further, after having already presented the gaussian interpretation for measurement fluctuations. At present, maintaining the same conceptual objectives [Ho98], the synthesis experiment was boosted up by dividing the students in each class into two groups which rotate between the traditional dice throwing activity and data taking with a Geiger-Müller counter, also of intrinsically statistical nature. In both applications data are collected in increasingly bigger samples to show the power and limits of statistical reasoning. The three first experiments deal with: (1) the timing of the oscillations of a pendulum in a progressively better controlled experimental situation; (2) the study of the relation between period and length of similar penduli consisting of a small lead bob on an almost inextensible string, graphical analysis of linearized relations being introduced, besides insisting on histograms and comparison of results; (3) the graphical analysis of an unknown relation, consisting of the study of crumpled paper balls [Go87], which are revealed as fractal objects (more histogramming and the first analysis through a gaussian representation, which is extended, through his complete report by each student, to all formerly histogrammed data).

The second block of experiments, also during the first semester, is concerned with improving the understanding of the concept of experimental uncertainties and their so-called *propagation* throughout the calculations performed with the primary measured values. It is always tried to present experimental situations which are a priori unknown to the freshmen and need propagation to be solved.

It is only in the third and fourth blocks, in the second semester, that the fit of the linearized relations through a least-squares procedure (and residue and chi-square analysis) is introduced to the students. At the same time, the significance of modelling is stressed and, especially through situations in fluid mechanics, its break-down in several important situation is demonstrated[Am97]. By the end of the fourth block, the majority of the students is able to work almost independently and seems to have understood at least the necessity of the usually adopted attitudes in dealing with experimental situations. Some of them will even have incorporated the essence of it. An experiment of free choice is the final task and serves also for evaluation purposes[Ho00].

VI - Group work of the teacher team and conclusions

To attain, both, conceptual as well as attitudinal objectives, a continuous reassessing of the didactic approach is practiced in weekly meetings of the teacher team, which last about two hours. These meetings, which discuss the previous and the next lab periods, besides priorities and difficulties, proved extremely useful, especially to tune the whole team to common objectives and attitudes. In these meetings the younger members give normally a very effective contribution. Several modifications were, as consequence, introduced along the years, especially in what refers to the way the experimental situations are presented to the students. Sharing of experiences has led, particularly, to an increasing emphasis on promoting discussions, first in smaller groups, then with all teams within each class and, finally, with all classes together, in what is called by the teacher team a *synthesis-class*[Ho98]. The experimental activities are presented to the students in written form at the beginning of the semester and each topic is supposed to have been read before schedule. More and more of the details on how to proceed are left out of the texts, during the semesters. No explanations whatsoever are given at the beginning of the activity, but the teacher assumes the role of a promoter of discussions and helps to synthesize the most relevant points whenever opportunity is apparent and, especially, at the end of each activity.

Various kinds of anonymous questionnaires have been applied to assess the course[Ho97,Ho99]. It is clear that the great majority of students is responding increasingly well to the chosen approach. Indeed, more positive than negative qualifying words were employed by them, in a characterization through three words of free choice[Ho99]. Further, most of the students act in unknown, but similar, experimental situations in an adequate manner, that is try to assess the reproductibility of the data and employ the concepts of the statistical theory of uncertainties in an operationally correct manner[Ho00]. The necessity of stating uncertainties was clearly absorbed[Ho99]. On the other hand, when, through the questionnaire, in a test or an interview, an attempt is made to get access to the deeper understanding of some concepts, it seems that several misconception still survive[Ho99]. This is to be better underpinned in the next few terms.

References

[Am97] M. Amaku et al., *Validade e Limitações de Modelos de Interpretação de Dados em Laboratório de Terceiro Grau: Alguns Aspectos de Fluidodinâmica*, XII SNEF, Belo Horizonte, 1997, in anais p. 119

[Am98] American Association of Physics Teachers, *Goals of the Introductory Physics Laboratory*, Am. J. Phys. **66**(6);483-485(1998)

[Be71] J.A. Beun, *Experiences with a Free Undergraduate Laboratory*, Am. J. Phys. **39**;1353-1356(1971)

[Ca86] E.H. Carlson, *Constructing Laboratory Courses*, Am. J. Phys. **54**(11);972-976(1986)

[Go87] M.A.F. Gomes, *Fractal Geometry in Crumpled Paper Balls*, Am. J. Phys. **55**(6);649-650(1987)

[Ho51] J. Hough, *The Fundamental Problems of Experimental Physics*, Am. J. Phys. **19**(9);489-499(1951)

[Ho97] L.B. Horodynski-Matsushigue et al, *Os Objetivos do Laboratório Didático na Visão de Alunos Ingressantes no Bacharelado em Física do IFUSP e de seus Professores*, Rev. Bras. Ens. Fís. **19**(2)287-297(1997)

[Ho98] L.B. Horodynski-Matsushigue et al, *Gambling as a Teaching Aid in the Introductory Physics Laboratory*, Eur. J. Phys. **19**;337-346(1998)

[Ho99] L.B. Horodynski-Matsushigue et al, *Incertezas Experimentais: É Possível Convencer os Alunos de sua Utilidade?*, XIII SNEF, Brasília, 1999, in Resumos p. 18

[Ho00] L.B. Horodynski-Matsushigue et al, *Assessing in the Laboratory: Can it be Significant?*, contribution to this Conference

[Iv68] J.W. G. Ivany and M.R. Parlett, *The Divergent Laboratory*, Am. J. Phys. **36**;1072-1080(1968)

[Jo94]R. Journeaux and M.G. Séré, *Traitement Statistique des Incertitudes en Physique: Problèmes Scientifiques et Didactiques*, Eur. J. Phys. **15**;286-292(1994)

[Jo98] A.H. Johnstone, A. Watt and T.U. Zaman, *The Students' Attitude and Cognition Change to a Physics Laboratory*, Phys. Edu. **33**(1);22-28(1998)

[Me70] J.C. Menzie, *The Lost Arts of Experimental Investigation*, Am. J. Phys. **38**;1121-1127(1970)

[Mi62] W.C. Michels, *The Role of Experimental Work*, Am. J. Phys. **30**;172-178(1962)

[Po84] J.G. Potter and J. Burns, *Alternative Justification for Introductory Physics Laboratory Courses*, Am. J. Phys **52**(1);12-13(1984)

[Ro79] M.C. Robinson, *Undergraduate Laboratories in Physics: Two Philosophies*, Am. J. Phys. **47**(10);859-862(1979)

[To83] W.S. Toothacker, *A Critical Look at Introductory Laboratory Instruction*, Am. J. Phys. **51**(6);515-520(1983)

[Va90]This decision was taken by the academic staff and heavily supported by A.G. de Pinho-Filho and V.R. Vanin

[Vu92] J.R. Vuolo et al, *Física Experimental I e II*, apostilas, IFUSP, São Paulo, 1999

[Vu96] J.R. Vuolo, *Fundamentos da Teoria de Erros*, 2nd Ed., Edgar Blücher, São Paulo, 1996

[Vu00] J.H. Vuolo et al., *Física Experimental I*, apostila, IFUSP, São Paulo, 2000

ATAS DA VII CONFERÊNCIA INTERAMERICANA SOBRE EDUCAÇÃO EM FÍSICA

PROCEEDINGS OF THE VII INTERAMERICAN CONFERENCE ON PHYSICS EDUCATION

Porto Alegre (Canela), Brasil 3 - 7 Julho de 2000 (July 3-7), 2000

Organizador (Editor)
Marco Antonio Moreira

Patrocínio (Sponsorship): **Conselho Interamericano para Conferências sobre Educação em Física** (Interamerican Council for Conferences on Physics Education); **Instituto de Física da Universidade Federal do Rio Grande do Sul** (Institute of Physics of the Federal University of Rio Grande do Sul); **Sociedade Brasileira de Física** (Brazilian Society of Physics).

Apoio Financeiro (Financial Support): **CNPq/Brasil: Conselho Nacional de Desenvolvimento Científico e Tecnológico** (National Council for Scientific and Technological Development); **ICPE/IUPAP: International Commission on Physics Education/International Union of Pure and Applied Physics** (Comissão Internacional sobre Educação em Física/União Internacional de Física Pura e Aplicada); **CAPES/MEC/Brasil: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior/Ministério da Educação (Coordination for the Development of Higher Education Personnel/Ministry of Education)**; **FAPERGS/RS/Brasil: Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul** (Research Support Foundation of the State of Rio Grande do Sul).

VII CIAEF, Brasil, 2000 / VII IACPE, Brazil, 2000

FICHA CATALOGRÁFICA
Preparada pela Biblioteca do IF-UFRGS
Por: Letícia Strehl – CRB 10/1279

C748a Conferência Interamericana sobre Educação em Física (7.: 2000 : Canela, Brasil)
Atas [arquivo de computador] / VII Conferência Interamericana sobre Educação em Física ; editada por (edited by) Marco Antonio Moreira. – Porto Alegre : Instituto de Física - UFRGS, 2000.
1 CD-ROM : il.

1. Educação em Física I. Moreira, Marco Antonio II. Título

CDU 53:37(063)
PACS F01.40.

Formatação: Adriana Marques Toigo
Paulo Azevedo Soave
Cao Trein