ASSESSING IN THE LABORATORY: CAN IT BE SIGNIFICANT?

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

lighia@if.usp.br

Abstract

To assess the skills, conceptual understanding and attitudinal growth, which may be fostered through laboratory activities, is universally recognized as difficult. A two semester course on introductory Experimental Physics engages about two hundred students majoring in Physics at the "Instituto de Física da Universidade de São Paulo" for four hours each week. The teacher team responsible for the course has developed a series of instruments to evaluate, besides the usual operational abilities, several of these higher goals of the teaching/learning process. Both, complete reports, in almost scientific format, and written tests are utilized, each with its specificities. Oral interviews, of two different kinds, are also employed in the first semester. One of the interviews has the purpose of checking the understanding, in the initial stages of the process, and the next of assessing the skills developed in measurement processes and the conceptual growth in data interpretation, at the end of the semester. As global evaluation of the whole teaching/learning process, a final experiment of *free* choice, but subjected to several important boundary conditions, which are here commented, provides valuable information. Most of the students performed very well on this *free* experiment, which has been employed with success during the last two years.

I - Introduction

To meaningfully assess skills and conceptual understanding is recognized as difficult by the teacher community, particularly also at the University level. This is especially true in an experimental discipline[Fr88,Ki88,Th83]. Throughout the world, marks for laboratory courses are mostly attributed with basis on written reports about experimental exercises and, sometimes, on written examinations.

It is well known that to do significant assessing, it is necessary to first define the main objectives of the teaching/learning process. As put forward in a recent report by the American Association of Physics Teachers-AAPT[Am98], a variety of objectives may be associated with the introductory laboratory and, in that study, they were grouped into five broad classes, named *goals* from I to V. When planning the actual laboratory, emphasis may be put onto two or three of these goals, but it is certainly almost impossible to attain any of the goals to a satisfactory degree, if priorities are not selected[Ho00]. Examining the objectives [Am98] in detail, it is seen that several include a desire to influence the attitudes of students toward Physics, Experimental Physics in particular, and their attitudes during the execution of tasks within the measuring and analyzing processes which characterize this special type of work. Therefore, on one hand, the didactic laboratory is meant to be able to attain an extraordinary quantity of attitudinal goals[Am98], but, on the other hand, those are exactly the less observed aspects in its assessing. Project work has been put forward, especially in the past, as an adequate means of, both, teaching and assessing the relevant experimental skills and attitudes. It demands, however, an enormous availability of human and material structure from the institution. In addition, if the project work is totally *open-ended*, it frequently does not lead to a successful result, at least in the view of the students, since it then resembles too much a real research work, without the concrete conditions to perform to such a degree.

At the "Instituto de Física da Universidade de São Paulo" (IFUSP), a team of teachers has been involved, for about ten years, in defining the main objectives of the introductory laboratory for Physics freshmen[Ho97,Ho99a,Ho99b,Ho00]. It boiled down to giving emphasis on having students collecting data adequately and performing their analysis correctly in pre-fixed experimental situations, which are not designed to reinforce physical concepts that are simultaneously taught at the so called *theory* classes[Ho00]. In this way, goal III "Conceptual Learning", as characterized by the AAPT report[Am98] is not a main aim of the course. Rather, experiments are selected so that they, *while asking a meaningful question to Nature*[Am98], introduce, in order of increasing difficulty, several concepts and skills which are particular to Experimental Physics[Ho00]. In this manner, students are slowly led to *walk their own ways*, after being introduced to some fundamental abilities. The first semester of a sequence of two is employed to convince the students that: data do vary, even if taken under seemingly *identical* conditions; care must be taken to avoid or detect systematic trends in data; and statistical analysis of uncertainties can be employed to convey the most important information contained in the data. The second semester, besides further stressing the aforementioned facts in other experimental situations, presents a more sophisticated method of analysis of experimentally established relations between two physical quantities, namely a least squares fit of straight lines to the linearized plots of the data. By giving due importance to the analysis of residues and the meaning of chi-square, two significant concepts are put into the foreground: that the theoretical model, applied at first sight, may not contain all the physically relevant aspects; and that, on the other hand, the uncertainties attributed to the primary quantities may not reflect all the manifold contributions to the complex process of measuring. Simultaneously, several attitudinal objectives are also pursued[Ho00].

As presented in the complementary contribution to this conference *Planing an Introductory Laboratory for Physics Freshmen: Ten Years of Growing Understanding at São Paulo University*[Ho00], the activities were divided into four blocks, each with a duration of about two months. About two hundred and forty students enroll each year to major in Physics at the central campus of the São Paulo University. In the two semesters of the introductory laboratory they work in class in teams of two, which are not maintained fixed, for four hours each week. Some extra-class work is also expected.

II - Assessing in the introductory laboratory

To assess the effectiveness of the varied activities employed in the teaching/learning process[Ho00] in the introductory laboratory and the resulting understanding and maturity, several instruments have been developed and applied along the preceding years in São Paulo. The teacher team is, by now, able to state that it knows how to significantly assess which of the goals were attained. This means also knowing how much the individual student, besides being (or not) operationally fit on several techniques, applications and skills which are characteristic of experimental work, has benefited from conceptual and attitudinal growth. To this end the following instruments are employed at present, with the stated purposes:

A - During the first semester, corresponding to blocks I and II[Ho00]

?? For the first two months (block I): a written report, by each student, about one experiment randomly chosen out of the four experimental activities, which had been already performed by a team of two students, after all the preliminary reports have been corrected by the teacher and returned to them[Ho00]. This final or *complete* report is to be written, as far as possible, along the guidelines for formal presentation and each section is graded separately. However, most of the final mark reflects how much the student has incorporated the guidance, which was given during the execution of the respective experiment and in the correction of its preliminary report[Ho00], trying to have him or her collecting and analyzing data properly. An interview based on the report is mandatory. This consists of fifteen to thirty minutes of a private dialogue between teacher and each student, where the teacher tries to evaluate the understanding of the experimental process which the student constructed and how much he or she is able to report scientifically on it, while the teacher gives hints on the accepted way. This interview results in a possibility of renormalizing the grade obtained on the report by ?15% of the maximum value. Before writing the report, students may attend a so-called synthesis-class [Ho97] which overviews the experimental results obtained by all classes during the two months. The purpose is to transmit confidence in the act of measuring and the habit of comparing outcomes critically. In this manner, the teacher team is trying to partly assess the goals I ("The Art of Experimentation"), II ("Experimental and Analytical Skills") and IV ("Understanding the Basis of Knowledge in Physics"), as they were enumerated by the AAPT [Am98].

?? For the second two months(block II): besides another complete report, on similar terms, a written test and a final interview. The test may be solved with the aid of any written material the student wants to take with him, but presents data of hypothetical experimental situations which are different in form, but absolutely similar in conceptual content, with respect to former analyses done in the lab. This written test was found necessary to evaluate effectively the individual assimilation of some main concepts and the learning of analytical skills, which are some of the declared objectives of the disciplines (Goal II of AAPT) and which may be concealed by the team work which resulted in the written report. The outcome of the test has been extremely positive in what concerns skills, as execution and interpretation of graphs and calculation of experimental results and their uncertainties. On the other hand, the tests confirm the difficulty of some concepts of the statistical theory of measurements, in particular of the standard deviation and its importance in the characterization of the experimental situation. The final interview, with a duration of thirty minutes, has the purpose of observing the attitudes of each student during a simple measuring process and of assessing (and if necessary try to guide him to) the adequate interpretation of the results (Goals I and II of

AAPT). If the teacher is sure that he or she has been able to observe this aspect of the learning process during the activities, and if the student agrees, this interview is not performed and the corresponding grade is incorporated into the one attributed to the written test.

?? The final grade of the semester is $N_F=(R_1+R_2+P+0.5E)/3.5$ where R_1 and R_2 are the grades of the reports, P that of the written test and E that of the final interview. The resulting grades are almost normally distributed around 6.5 on an increasing scale of 0 to 10, with a standard deviation of about 2.

B - During the second semester, corresponding to blocks III e IV[Ho00]

?? For the first two months: a complete report on similar terms, but expecting a greater maturity, as revealed through the quality of the discussions and conclusions (More relative emphasis on Goal IV.).

?? Finally, for the second two months: another written report, a written test with the same characteristics as the former one, but dealing with more complex themes and an experiment of free choice, to be further explained in item C. An optional final interview (according to the teacher's choice) may also be scheduled.

Appendixes A and B show examples in Portuguese of the tests presented recently to the students, respectively, at the end of the first and second semesters. It may be noticed that the tests contemplate experimental situations which are different from what is presented in the laboratory [Ho00], but may be solved through completely similar analysis procedures, which is exactly the purpose of this particular form of assessment. As long as the tests are in use, that is since 1995, no particular problem-situation was employed more than once.

C - Global evaluation

?? And last, but definitely not least, an important instrument for a global evaluation of the teaching/learning process, is the new, so-called *free* experiment, to be proposed by each student team at the end of the second semester. Practice has shown that to be successful, this activity should be constrained by important boundary conditions: the student team has to present clear and simple objectives for this *free* experiment, to be pursued with the use of the materials which, either, already exist at the laboratory or may be provided by the students themselves. No simple copy of existing instructions is accepted (for example: of other lab disciplines). A proposal which details, besides the objectives, the procedures for measurement and analysis must be forwarded three weeks before schedule. This proposal is analyzed by two teachers and discussed with the student team. Too *open-ended* or poor activities are redirected in this discussion, which is extremely important in the whole process. Sometimes, more than one interview is needed, but finally more than 80% of the proposals come to a good end. For those who are unable to do so, an alternative experiment with rather cumbersome procedures is presented, in the usual format. Assessing is done considering the entire activity, that is: (*i*) the quality of the proposal, where inventiveness is not the primary aspect, but rather clearness of objectives, an adequate proposal for experimental procedures (along the lines stressed during the two semesters) and for data analysis (employing the instruments introduced during the disciplines, in particular the statistical aspects); the grade corresponding to this item is lost by the team who was unable to present an acceptable proposal; (*ii*) the experimental abilities demonstrated during the execution; (*iii*) the quality of the analysis employed and the consistency of the conclusions drawn; and (*iv*) the report, in short format, presented for this experiment. Short seminars of fifteen minutes, besides the report, help to disseminate the results which each team has obtained. Although these seminars provide another opportunity for assessment, they do not correspond to a separate grade, but may modify the points attributed to the activity by ?15% of the maximum allocated to it. This was decided upon, since students are not previously trained in seminars and therefore only extremes in performance, either excellent or very bad, should be taken into account. In spite of its importance, for now, the teacher team decided not to grade this activity too high and also that both students of the team should receive the same grade, L. This type of global assessment, which touches on almost all the goals of the AAPT report, has been employed for the last two years and has received approving comments from many students[Ho99a].

?? The final grade of the second semester is $N_F=(R_1+R_2+P+0.5L)/3.5$ where R_1, R_2, and P have the meaning stated before.

Appendixes C and D present, respectively, the instructions forwarded to the students about the *free* experiment and some of the themes pursued by them in this activity. It may be noted that, although the themes are sometimes very similar at first sight, each team's approach is definitely different.

III - Conclusion

As formerly stated, the teacher team in São Paulo is, at present, basically satisfied with the evaluation procedures that have been employed during the last years. An important point, to be especially stressed, is that the manner in which assessing has been done over the recent semesters takes much of the pressure for grades, which students usually exert, away from almost all activities. Students seem to perceive their growing understanding of Experimental Physics and to see grades as being in correspondence with it. The double correcting of the lab reports[Ho00], first only about the essentials of data analysis on a pre-report handed in by the student team (which is, not graded) and later, again on two complete reports in each semester, these ones produced by the individual student in conformity with scientific writing (utilizing the pre-report as a basis), is an important instrument in the learning process, although it demands a somewhat greater effort of the teacher.

Within its many evaluating procedures, the teacher team is putting an increasing emphasis on the *free* experiment, which also results in valuable feedback for the teaching process, since it assesses most of the higher skill, conceptual and attitudinal learning, in accordance with goals I, II, IV and V, as classified by AAPT[Am98], where goal V refers to "Developing Collaborative Learning Skills". The very autonomous way most student teams conducted *their* experiment and how well they worked as a *group* was very reassuring to everybody involved, students and teachers.

Finally, it is to be pointed out that each of the instruments employed for the assessing of the students is, in fact, another source of great value, since it provides information for the continuous re-planning of the course[Ho00]. In particular, preliminary and complete reports are commented in the weekly meetings of the teacher team and serve on short terms to guide the discussion that the teachers try to foster in class.[Ho00]

Open questionnaires (of the type: characterize your two semesters disciplines through three words) showed, furthermore, that more positive than negative aspects were associated with Experimental Physics[Ho99b].

References

[Am98] American Association of Physics Teachers, *Goals of the Introductory Physics Laboratory*, Am. J. Phys. **66**(6);483-485(1998)
[Fr88] A.P. French, *Some Thoughts on Introductory Physics Courses*, Higher Education **17**;81-98(1998)
[Ho97] L.B. Horodynski-Matsushigue, P.R. Pascholati, J.H. Vuolo, M.-L. Yoneama, J.F. Dias, P.T.D. Siqueira e M. Amaku, *Uma Proposta para o Laboratório Didático de Física no Primeiro ano do 3° Grau: Física Experimental I e II no IFUSP*, XII Simpósio Nacional de Ensino de Física-Novos Horizontes, 27 to 31-jan-1997, Belo Horizonte, in Proceedings p. 100
[Ho99a] L.B. Horodynski-Matsushigue, E.M. Yoshimura, E.W. Cybulska, N.H. Medina and P.R. Pascholati, *Um Experimento Optativo como Avaliação de Aprendizagem em um Curso Introdutório de Laboratório de Física*, XIII Simpósio Nacional de Ensino de Física, Brasília, 25 to 29-jan-1999, in Caderno de Resumos e Programação, p. 18
[Ho99b] L.B. Horodynski-Matsushigue, E.M. Yoshimura, E.W. Cybulska, N.H. Medina and P.R. Pascholati, *Incertezas Experimentais: É Possível Convencer os Alunos de sua Utilidade?*, XIII Simpósio Nacional de Ensino de Física, Brasília, 25 to 29-jan-1999, in Caderno de Resumos e Programação, p. 18
[Ho00] L.B. Horodynski-Matsushigue et al, *Planing an Introductory Laboratory for Physics Freshmen: Ten Years of Growing Understanding at São Paulo University*, contribution to this Conference
[Ki88] P.A. Kirschner and A.M. Meester, *The Laboratory in Higher Science Education: Problems, Premises and Objectives*, Am. J. Phys. **56**;110-113(1988)
[Th83] G. Theysohn and H.-J. Jodl, *Testing Laboratory Performance*, Am. J. Phys.51;334-338(1983)

Appendix A

Example of the tests presented to the students at the end of the first semester.

Física Experimental 1 - FEP113
Prova Final - 01/07/99

Cada aluno pode consultar livremente o material de que dispõe.
Note que a pontuação máxima desta prova soma 12 e que, por outro lado, o tempo é exíguo para completá-la, sugerindo que sejam feitas opções.
A duração da prova é de 3 horas.

QUESTÃO 1: A caracterização de uma máquina de produção de pãezinhos comuns foi feita realizando (com uma balança que tem incerteza instrumental de 1 mg = 10^{-3} g) medições da massa M de 400 pãezinhos por ela produzidos (série 1 - não mostrada aqui), obtendo-se uma massa média de $\overline{M}$ = (50,42? . . .) g com ? = 2,1 g (? é o desvio padrão). Um mês depois, foram feitas medições, com o mesmo equipamento, da massa de 7 pãezinhos (série 2) para confirmar se as características de produção não se alteraram.

A Tabela 1.1 apresenta os resultados das medições da série 2.

Tabela 1.1: Valores de massa dos pãezinhos (série 2).

M(g)
50,37
50,45
49,27
50,85
51,10
49,48
49,46

a) (0,5) Apresente o valor médio da massa dos pãezinhos da série 2.
b) (1,0) As características relevantes da máquina na produção dos pãezinhos melhoraram ou pioraram no segundo teste? Indique claramente o(s) critério(s) utilizado(s).
c) (1,0) Compare as massas médias dos pãezinhos produzidos no primeiro e segundo testes e verifique se elas podem ser consideradas iguais. Justifique as suas afirmações.
d) (1,0) O padrão do país é de pãezinhos com massa M_p = 50,0 g , permitindo-se variação de 5% na massa destes pães. Analise se a produção da padaria obedece esse padrão.

QUESTÃO 2: A revista QUATRO RODAS realiza periodicamente testes de carros modernos. Nos testes de frenagem são medidas as distâncias de frenagem (d), isto é, as distâncias percorridas até a parada total, em função da velocidade inicial (v). Na Tabela 2.1 estão apresentados os dados obtidos neste teste para um carro modelo Z3 da montadora BMW.

Tabela 2.1: Distância de frenagem (*d*) em função da velocidade inicial *v*.

v(km/h)	*d*(m)
20,0	1,85?0,25
40,0	7,1?0,4
80,0	27,1?1,2
120,0	64,7?2,1

Com estes dados pode-se determinar a relação funcional entre distância de frenagem e velocidade, isto é, a equação da variável *d* em função da variável *v*.

a) (2,0) Faça o gráfico em papel adequado onde seja possível obter uma reta com os dados da Tabela 2.1, mantendo-se as unidades indicadas nesta tabela.
b) (0,5) Qual seria distância de frenagem, neste teste, para a velocidade inicial do carro de 100 km/h.
c) (0,5) Um perito da polícia, vistoriando um acidente de um carro deste modelo, percebe que a distância de frenagem do carro foi de (21,0?1,1) m. Que conclusões o perito pode tirar sobre a velocidade do carro no início da frenagem?
d) (1,0) Determine o cœficiente angular da reta traçada no gráfico da questão a).
e) (0,5) Escreva a relação funcional para as variáveis *d* e *v* (a equação completa com os valores numéricos de todos os parâmetros).
f) (0,5) Interprete fisicamente a equação obtida.

QUESTÃO 3: Um estudante imaginou uma experiência para determinar a densidade linear ? (definida como massa por unidade de comprimento) de um fio de nylon. Cortou o fio em vários pedaços e obteve dados com os quais construiu a Tabela 3.1 e o gráfico da Figura 3.1.

Tabela 3.1: Valor do comprimento dos pedaços do fio e suas massas.

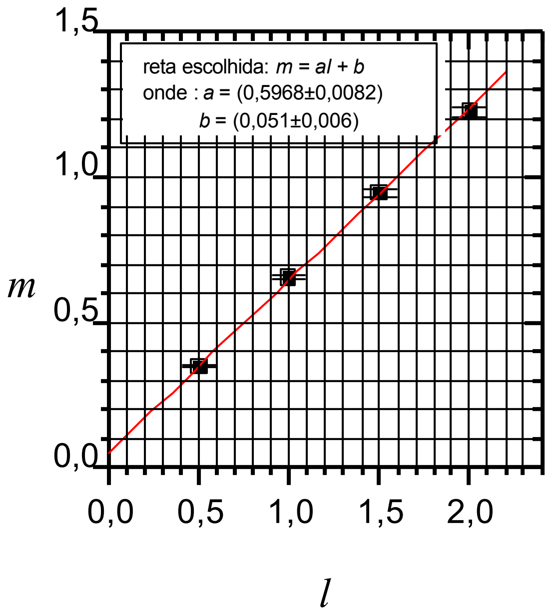
l?0,002(m)	*m*(g)
2,000	1,227?0,016
1,500	0,948?0,012
1,000	0,654?0,008
0,500	0,349?0,004

a) (0,5) Complete o gráfico, com todas as unidades faltantes.
b) (0,5) Comente o gráfico, em particular dê uma interpretação física aos coeficientes apresentados.
c) (0,5) Determine o valor e sua incerteza para a densidade linear do fio.
d) (0,5) O diâmetro do fio foi fornecido pelo fabricante como sendo ? = 0,80 mm. Atribua-lhe uma incerteza e justifique a sua atribuição.
e) (1,0) Obtenha a densidade volumétrica do nylon (*d*) com o qual o fio, suposto cilíndrico, foi confeccionado; calcule a sua incerteza.

$$d \; ? \; \frac{4a}{??^{2}}$$

f) (0,5) Qual é a massa de um pedaço de 75,0 cm do fio em questão, cortado de forma idêntica?

Figura 3.1: Massa em função do comprimento dos pedaços de fio de nylon



Appendix B

Example of the tests presented to the students at the end of the second semester.

Física Experimental 2 - FEP114
Prova Final - 24/11/98

Cada aluno pode consultar livremente o material de que dispõe.
Note que a pontuação máxima desta prova soma 12 e que, por outro lado, o tempo é exíguo para completá-la, sugerindo que sejam feitas opções.
A duração da prova é de 3 horas.

QUESTÃO 1: Um experimentador munido de uma panela cheia de água, um termômetro de termopar (menor divisão 0,1^{o}C) e um cronômetro, resolve estudar como a água entra em equilíbrio térmico com o meio ambiente em função do tempo. A água foi aquecida até aproximadamente 80^{o}C, através de um aquecedor elétrico e anotou-se a temperatura em função do tempo de resfriamento, sendo os resultados apresentados na Tabela 1.1. Tomou-se o cuidado de agitar continuamente a água para manter a temperatura uniforme. Considere que o resfriamento da água segue uma lei exponencial do tipo ?T=?T_o $e^{-t/?}$, onde ?T é a diferença entre temperatura da água e a do ambiente, ?T_o é a diferença de temperatura inicial, ? é a constante de resfriamento e t o tempo decorrido.

a) (0,5) Considerando-se que a temperatura ambiente ficou constante durante a tomada de dados com o valor T_{amb}= (26,9 ? 0,3)^{o}C, obtenha as diferenças de temperatura (?T) e as respectivas incertezas.
b) (1,5) Faça o gráfico adequado para o estudo do resfriamento da água.
c) (1,0) Obtenha graficamente a constante de resfriamento (?) e sua incerteza.

Tabela 1.1: Temperatura da água em uma panela, em função do tempo.

T(^{o} C)	tempo (min)
74,1	0,0
62,6	10,0
55,0	20,0
48,1	30,0
41,6	45,0
36,7	60,0
34,6	70,0
32,7	80,0
31,5	90,0
30,5	100,0

QUESTÃO 2: Numa determinada região da cidade de São Paulo, abrangendo 50km^2, existem 4 estações de acompanhamento do regime de chuvas, cada uma com um tanque coletor de formato cilíndrico, mas com área diferente. Após meia hora de coleta, num dia de verão, durante uma chuva, forte, uniforme e contínua, as estações forneceram os dados apresentados na Tabela 2.1.

Tabela 2.1: Volume de água coletada (V_C), em litros, durante meia hora de chuva forte, uniforme e contínua, em quatro coletores, cujas áreas (A) são fornecidas. Os números entre parênteses representam a incerteza associada ao valor da grandeza (por exemplo, 51,3(8) = 51,3 ? 0,8).
1 ℓ = 1 dm^3 = 10^{-3} m^3.

Estação	**A (m^2)**	**V_C (ℓ)**
A	1,023(2)	51,3(8)
B	0,542(2)	25,8(8)
C	1,638(2)	83,4(8)
D	2,056(2)	102,5(8)

a) (2,5) Encontre, através de uma análise gráfica dos dados da Tabela 2.1, o valor da precipitação (z), em mm/hora (define-se precipitação como a altura da coluna d'água de chuva precipitada por unidade de tempo), acompanhado por uma estimativa de incerteza. Indique claramente como obteve os valores.

b) (1,5) Um meteorologista afirma que, após análise dos dados por ajuste com uma função linear do tipo ($y_m = ax + b$), que fornece **V_C** como função de **A**, obteve para os dois coeficientes os valores: a = 50,8(2) ℓ/m^2 b = 0,020(5) ℓ. Represente esta função no gráfico e faça uma análise dos resíduos ($r_i = y_i - y_m$, onde y_i é o valor experimental), comentando sobre a verossimilhança da reta obtida pelo meteorologista.

c) (1,0) Existe um único rio na região e, devido à impermeabilidade do solo, (80 ? 5)% do volume de águas de chuva é drenado até ele. Obtenha o volume total (em m^3) de água que o rio receberá, se a chuva aqui descrita continuar em toda a região e com as mesmas características por 5,3(1) horas.

QUESTÃO 3: Alunos do curso de Física Experimental II de 1998, fizeram uma experiência para determinar a velocidade de propagação de som no ar. Os resultados destas 78 medidas es-tão apresentados no histograma da Figura 3.1. O valor médio da velocidade de som foi calcu-lado em $\mathbf{v_m}$ = 347,1 m/s e a temperatura ambiente durante as medidas era de 22,1 ? 1,8 ?C.

a) (1,0) Analisando o histograma estime o valor do desvio padrão desta distribuição. Justifique.

b) (0,5) Apresente o valor médio da velocidade de propagação do som e sua incerteza. Justifique.

c) (0,5) Compare os resultados desta experiência com os valores da velocidade do som em função da temperatura apresentados na tabela 3.1. Justifique.

Figura 3.1: Histograma das velocidades de propagação do som obtidas pelos alunos de FEP114.

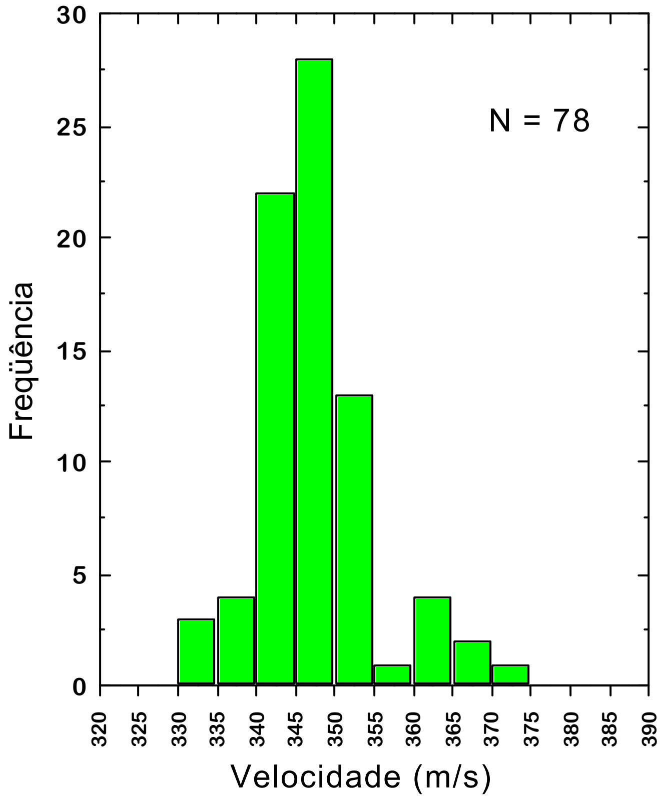


Tabela 3.1: Valores tabelados da velocidade de propagação do som no ar seco em função da temperatura (Ref. Quadro do Laboratório Didático).

T (?C)	v (m/s)
20	343,37
21	343,95
22	344,54
23	345,12
24	345,70
25	346,29
26	346,87
27	347,44
28	348,28

QUESTÃO 4: (2,0) Faça um resumo (nos moldes de um resumo para relatório) de um dos três últimos experimentos realizados por sua turma.

Appendix C

Instructions forward to the students in preparation of the *free* experiment.

Experiência 6 de Física Experimental II
(Experiência proposta pela equipe de alunos)

1 - Objetivos didáticos

Esta atividade tem como finalidade colocar o aluno em uma situação em que ele seja estimulado a por em prática de forma mais autônoma os conhecimentos sobre metodologia de tomada e análise de dados, adquiridos ao longo dos 2 semestres de Física Experimental 1 e 2. Assim, a equipe de alunos deve escolher equipamentos que lhe sejam suficientemente familiares. Além disso, é essencial que seja proposta uma experiência cujos objetivos contemplem o emprego do ferramental estatístico desenvolvido durante as referidas disciplinas na análise quantitativa de dados.

2 - Detalhamento das atividades a serem cumpridas na experiência e cronograma

1. ESCOLHA DO TEMA E DOS OBJETIVOS DA EXPERIÊNCIA - deve ser feita em função dos equipamentos disponíveis e que estarão, em parte, em exposição na semana de 05 a 08/10, juntamente com o auxílio de um monitor; qualquer material adicional deve ser pesquisado pela equipe e por ela providenciado.
2. Desenvolvimento da proposta, a partir do tema escolhido, com a FIXAÇÃO DE OBJETIVOS concretos e viáveis;
3. Desenvolvimento da PROPOSTA DE PROCEDIMENTO, experimental e de análise, que viabilize a obtenção das metas;
4. DISCUSSÃO (opcional) da proposta desenvolvida nos itens 2 e 3 com o professor, para verificar a viabilidade de sua execução (em horário a combinar com o professor, antes da aula da semana de 13 a 16/10);
5. Apresentação oficial da PROPOSTA DE EXPERIÊNCIA: no começo da aula da semana de 13 a 16/10/98;
6. Julgamento da PROPOSTA por dois professores da equipe, retorno do resultado aos alunos no plantão de dúvida ou até a aula da semana de 19 a 21/11;
7. Realização de medidas EXPLORATÓRIAS (1ª semana da 6ª experiência);
8. Refinamento do procedimento e medições definitivas (1ª e 2ª semana da 6ª experiência);
9. Análise preliminar (1ª e 2ª semana da 6ª experiência);
10. Análise definitiva e síntese (2ª semana, até o prazo usual de entrega de síntese);
11. Após análise e correção da síntese pelo professor, preparação de pequeno seminário para a disseminação da experiência executada com as outras equipes de alunos.
12. Avaliação da Atividade: A equipe será avaliada em todas as etapas da execução e na apresentação da 6ª experiência. A nota da avaliação L é contemplada com peso 0,5 na média final do semestre.

3 - Formato de PROPOSTA DE EXPERIMENTO

Trata-se de proposta com 1 a 2 páginas (só manuscritos) em que o aluno deve deixar sucintamente claros os seguintes itens:

1. objetivos (principal e secundários, se existirem);
2. procedimento básico para tomada de dados;
3. descrição da análise de dados a ser empregada;

4. material a ser empregado.

4 - Procedimento caso a proposta entregue não seja julgada satisfatória

O aluno será obrigado a desenvolver melhor a proposta ou escolher outra, perderá o direito de executar o experimento na 1ª aula da 6ª experiência e terá o seu tempo de medida e análise restritos a 2ª aula.

5 - Equipamentos disponíveis

Estão disponíveis todos os equipamentos utilizados nas disciplinas Física Experimental 1 e 2; podem, também, ser utilizadas outras montagens existentes nos laboratórios didáticos. Algumas das mesmas estarão em exposição na semana de 05 a 08/10. Aparelhagens complementares poderão ser solicitadas aos técnicos e serão fornecidas, se disponíveis. Não é permitida a simples transcrição e repetição de algum experimento realizado em disciplinas oferecidas pelo IFUSP, excetuando-se a procura de uma melhora considerável nas condições experimentais e na precisão (e exatidão, se possível) do resultado.

Appendix D

Some of the themes selected by the students for the *free* experiment and their practical development during the activities in 1998 and 1999.

Examples are grouped arbitrarily and try to show the most prevalent types of studies.

I – Studies dealing with springs (very popular, since they were used extensively as example in *theory* classes):

a) relation between the spring constant *k* (obtained experimentally in the static approach) and the period of oscillation of a spring/mass system for several springs and masses, *m*, (1998);
b) tentative of establishing the relation between the spring constant and several characteristics of the spring (diameter of the wire, length of the spring, diameter of the coils, material of the wire, etc.) (1998);
c) precision investigation, trying to establish at which level the apparent similarity of two springs would break down (1998).
d) study rather similar to that of a) of the previous year, but made for other kinds of springs and with a somewhat different procedure (1999);
e) comparison of the predicted period (from *k* and *m* taken experimentally), for three springs with spring constants *k* differing by a factor of two between each two of them, with that verified through timing. A study was also made to verify the spring constants resulting from series and parallel associations of the three springs (1999).

II – Studies dealing with pendulums and resonating systems

a) relation between the resonance frequency and the length of a guitar wire, simulating playing conditions (1998).
b) relation between the period of oscillation and the point of suspension of a metallic bar (1999);
c) relation between period of oscillation and amplitude of a simple pendulum of given length (1999);
d) energy loss during the oscillation of a pendulum, measured as decrease of the maximum height attained in the gravitational field (1999).

III – Studies related do liquids

a) determination of the density of several liquids, measuring (through a previously calibrated spring) the buoyancy they exert on objects made of the same material, but with different volumes (1999);
b) coefficient of volume dilatation of glycerin obtained with a picnometer immersed in a well-controlled water bath (1999);
c) viscosity of motor oil, through the terminal velocity of small metal spheres in a vertical oil column maintained at controlled temperature: study of the breakdown of Stokes' law as a function of the diameter of the sphere (1999).

IV – Studies related to resistivity (there are always some students which are curious about this phenomenon and they mostly start proposing to obtain the resistivity of copper wires(!!))

a) resisitivity of NiCr wires as function of length and diameter (1998);
b) resistivity of graphite bars (from pencils) as a function of length and diameter, immersed in water to control the temperature (1999).
c) similar to a), but utilizing an old rheostat and obtaining the resistence as function of the number of coils; they supposed to be using NiCr, but concluded, correctly, that the rheostat was made of another material (1999);
d) assessment of the variations of the resistence of lots of commercial carbon resistors, with nominally 100? values (1999);
e) determination of the resistence of a commercial diode as a function of temperature, with the purpose of constructing a thermometer.

V - Studies related to precision/accuracy of equipment

a) energy loss of a didactic calorimeter to its surroundings (1999);
b) repeatability and accuracy of a mass scale (1999).