Learning objectives in the physics lab

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INTRODUCTION

Traditionally, the physics laboratory is an important part of physics training, with the understanding that students should learn experimental techniques (including methodological aspects such as discussions of measuring precision) while studying fundamental physical phenomena.
Nowadays, the cut-down of resources for lab work and the emergence of new experimental techniques - such as virtual labs and remote labs [1] - appear to question the traditional concepts of physics labs. In order to assess the potential of these new methods, it is important to consider in detail the whole spectrum of learning objectives that might apply to a physics lab, in order to see which objectives are matched by the new forms and which ones are not [2,3]. There are several other reasons why I consider it advantageous to re-think lab learning objectives in order to get experiments better focussed and to help students to learn more efficiently and to increase their motivation.

1 WHY RE-THINK LEARNING OBJECTIVES

Traditionally, physics has been considered a prerequisite of engineering studies, because engineering approaches rely on physical description of the technical world. Nowadays, however, technical disciplines have evolved to a point where they get along on their own. The importance of physics teaching for engineers therefore shifts from phenomenology to what may be called "physical thinking", i.e. the ability to go back to basic models and fundamental principles for getting solutions to new and as yet unsolved problems, being able to estimate the feasibility of new ideas [4,5]. The design of lab sessions should reflect this shift in the overall view of the role of physics in engineering studies. In addition, learning objectives in the lab should be explicitly formulated and explained to the students. The new didactic paradigms ask for more autonomy and responsibility of students in their learning process. In order to be able to take their responsibility, students should be well informed about what competencies to acquire and how to get there in an efficient way.

2 THE GREAT VARIETY OF LEARNING OBJECTIVES

Learning objectives in the traditional physics lab are often implicit - it is simply assumed that working with instruments and measuring physical phenomena would lead to understanding both of handling instruments, applying methods and understanding those phenomena from a physical point of view. More detailed inspection reveals that the learning objectives can be extremely varied. In this contribution, I would like to recommend to evaluate in detail in each case what the dominant learning objectives should be and to declare them explicitly so that the students know precisely what they are asked to do. I am convinced that such an analysis will improve the set-up of experiments, the redaction of accompanying manuals and the way students work and write their reports. In addition, it will be evident that only part of these objectives can be reached by modern alternatives to the traditional hands-on lab such as remote or virtual labs. As a consequence, lab work should be varied in its style to accommodate the various objectives.

3 THE LEARNING OBJECTIVES IN THE LAB

The main objectives come in two groups: measuring techniques and conceptual learning. Looking more closely, both of these groups appear to be extremely varied:
Measuring techniques include the handling of instruments, the capture and display of data, analysis of data (graphs), the evaluation and interpretation of data and error analysis.
Whereas usual practice combines all of this, assuming that students will learn all of it at the same time, it may be argued that it is in fact advantageous to focus their attention on specific aspects, either instrumental or related to data handling. Personally, I have made very good experiences with lab sessions where the emphasis was on how to draw graphs, how to interpret them, how to get information out of them, e.g. by re-plotting in an intelligent way [4]. Of course, the data used for this exercise had to be obtained from a simple, but attractive experiment - lab work should in any case stimulate students' interest and push them to ask new questions about the method as well as about the system they are working with. In other cases, the emphasis can be more on the instrumentation - data sheets could be made available, more advanced use of the instrument explained etc. This is most interesting for students if real industrial or research equipment is being used - of course with the necessary precautions.

On the other hand, studying physical concepts is perhaps the most common ingredient in physics labs (and the major aspect in virtual or remote labs): doing an experiment, a physical phenomenon is studied, as a pure demonstration or else analysing its dependence on measuring parameters. In fact, experimental observation can be extremely helpful for students to understand more complex notions like e.g. the moment of inertia or the angular momentum [4,6,7]. Such aspects are mostly studied in the lab after the corresponding notion has been treated in the lecture. However, it is equally conceivable to introduce physical notions by a lab experiment first and come back to it in the lecture afterwards. Of course, setting up the experiment and the accompanying manual will be very different in the two cases.
It is still a different thing to study a given phenomenon as a function of outer variables, e.g. viscosity as a function of temperature or flexion of a beam as a function of supported length. Again, this could come as a verification of what has already be learned in a lecture or as a complement to the lecture (as an example, I

do not treat the force between condensor plates in the lecture, but leave this as an exercise for the lab).
A special form is the "open lab" where the outcome of the experiment is not given from the beginning, but much freedom is left to the students about how to use the apparatus for looking into interesting questions. Whereas this form of laboratory is typically more appropriate for students at the end of their training, it can in some cases also be used for beginners in order to stimulate their curiosity [8].

The following listing is meant as a more systematic summary of the possible lab objectives mentioned above:

A) measurement oriented
- instrumentation: handling, precautions, safety, possible advanced application
- measurement process: careful reading, instrumental precision, repeatability, data acquisition
- representation of data: tables, graphics, different possibilities of plotting
- evaluation and interpretation of data: fits, linear re-plotting, limiting behaviour, special values
- measuring precision and "error analysis" of measured and evaluated data

B) concept oriented
- introducing a new phenomenon
- reviewing and analysing a known phenomenon
- introducing a new physical notion or concept
- reviewing, applying, analysing a known notion or concept

C) problem oriented
- "open lab" with the possibility of asking own questions and trying out
- project work

4 MAKING THE OBJECTIVES EXPLICIT

Typically, experiments in the lab will include several of the mentioned objectives simultaneously, because they always include some instrumentation as well as gathering and interpreting data. However, I would suggest to analyse in each case what the dominant aspects should be, to set up the experiment accordingly and to tell students explicitly what the objective is and what they should learn in the first place. E.g. if instrumentation is most important, it could be advantageous to try out other functions of the instrument than those strictly needed for one physical experiment. If the emphasis is on data handling, the acquisition of data should be simple and short (but interesting!) in order to let time for the discussion of correct representation, evaluation and interpretation. If the emphasis is on physical concepts, the link to the lecture should be made clear and the methodological effort should not be dominant (e.g. data acquisition, representation and evaluation should already be sufficiently trained in order not to divert the attention from the main topic of the session). Telling the students in advance what the main learning objective is, may be extremely important (unfortunately, in my personal experience, this aspect is often forgotten). Generally, it has been found out that students' learning is much more effective if they are told before the lecture what they are thought to learn in it [9]. The same should be true for lab work: Telling students where the main intention of the session is, whether on instruments, methods or concepts, will give them the opportunity to focus their attention on that aspect and to perform better and learn more efficiently.

5 ADAPTING THE SET-UP

Given the very different possible objectives of lab experiments, the instrumentation can be chosen accordingly. If instrumentation is the most interesting point, well performing instruments should be used, if possible at least with an outlook to industrial or research standards. If the emphasis is on data handling or physical concepts, the instrumentation does not really need to be sophisticated. The famous Berkeley Physics Course contains numerous indications for simple home experiments students could do. In the same way, simple equipment in the lab can also give students some ideas how to continue experimenting by their own. E.g. in order to study diffraction phenomena, a laser pointer directed onto a loosely woven tissue can give perfect results, allowing to determine the distance and thickness of threads in the tissue - such experiments can be put up in large numbers at low cost and will probably stimulate students' attention and curiosity more than a sophisticated diffraction apparatus in a remote lab.

It should be clear, that some of the more recent variations of lab work, virtual or remote labs, can be useful for some of the mentioned objectives, in general rather for the more conceptual ones, but not so much for the more methodological aspects. The learning objectives listed above could be very helpful in defining what students are really meant to learn and whether one or the other experimental set-up is really appropriate.

Personally, I think that the instrumental and methodological experience is very important for engineering students and that these aspects should therefore form an important part of lab work in their studies, possibly right from the beginning of their studies and not only in advanced studies and the thesis work. Though there may be a real challenge from the point of view of organisation and financial resources, this point is too important to be sacrificed.

6 CONCLUSION

In summary, I strongly suggest not to keep too many learning objectives lumped together in a physics lab session, but to define clearly what the main objective(s) are and to arrange the lab situation accordingly. Virtual labs cannot satisfy all of the possible objectives and should at least be complemented by other forms of more direct hands-on activities allowing to get in touch with instruments and the measuring process. As a major conclusion, learning objectives should be told explicitly to the students in order to focus their attention to the most important aspects, and their reports should be assessed according to these objectives.

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