Towards Renewed Research Questions from the Outcomes of the European Project Labwork in Science Education

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ABSTRACT: A research project about labwork at Upper secondary and Undergraduate levels was launched in 1996, funded by the European Commission. Seven research groups from six European countries participated in the surveys at European scale and carried out a number of case-studies. This common work allowed numerous discussions which, months later, permit to articulate renewed directions of research about labwork. In this paper, new research questions are presented, drawing upon the outcomes of the project. One of them was to disclose numerous potential objectives which can be aimed for in a laboratory. This means that conscious choices must be taken among objectives. These are studied in this paper under the three classical headings of conceptual/epistemological/procedural objectives.

FOREWORD

In October 1995, the European Commission’s General Directorate for Research (DGXII) selected 10 research projects in the frame of “Targeted socioeconomic research.” This selection included topics such as education of disabled children, university assessment, and science education. The project coordinated by the author was entitled “Improving Science Education: Issues and Research on Innovative Empirical and Computer-Based Approaches to Labwork in Europe” (Séré, 1998).

The intention of the project was to address the problem of the effectiveness of labwork, which in most countries is recognized as being essential to experimental sciences, but which turns out to be expensive and less effective than wished. The project lasted 2½ years, long enough to establish a realistic picture of the reality of labwork in the seven countries involved: France (coordinator), Denmark, Germany, Great Britain, Greece, Italy, and Spain. This period was also sufficient to establish a thorough mutual knowledge shared by the partner research groups and to initiate a number of case studies in various directions, in addition to surveys at the European level, as described in the annex. However, 3 years

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were not long enough for maturation. Having discussed and disseminated the results, as required by the European Commission, it is now worthwhile to draw conclusions and to recognize that the work carried out by the 38 members will contribute to the future directions of research on labwork. This is the aim of the present paper. The intention is not to give results, which are published elsewhere (see references), but
to demonstrate that certain avenues of research have now been completed, forming a solid basis for future research. No need to repeat them again.
other directions of research are now wide open and offer promising possibilities, that we attempt to identify in this paper.

INTRODUCTION

The general purpose assigned to the project “Labwork in Science Education” (LSE) was to enhance the effectiveness of labwork and to provide ideas to improve existing labwork or conceive new types of practical activity. The work was based on existing studies and, to some extent, followed on from previous results. They can be found in various reviews (Lunetta & Tamir, 1979; Woolnough & Allsop, 1985), in the final report of “Labwork in Science Education,” and in the proceedings of the conference “Practical Work in Science Education” organized by the Danish partner 1 month after the end of the project (Leach & Paulsen, 1999). Hereafter, among all these studies, we will consider only those at the level addressed by the LSE project: towards the end of secondary education, which means the end of upper secondary school and undergraduate level studies. The reality of labwork at these levels is rather different from what it is at other levels. Students of this age (16 – 20 years approximately), in all European countries, are required to manipulate truly complex theories and concepts. Generally speaking, students are expected
- to understand theory (concepts, models, and laws) as described in textbooks and labsheets, or as explained during lectures;
- to learn concepts, models, and laws;
- to do various experiments, using different pieces of theory and different procedures, in order to acquire a significant experience;
- to learn to “do again” the same experiments, and to follow the same procedures as utilized during preceding sessions;
- to learn processes and approaches and be able to apply and follow them in other contexts;
- to learn to use scientific knowledge, think with it, as experts do, and acquire the capacity to manage during a complete investigation.

As it can be seen from this list, the benefits are not only in terms of “to understand” and “to learn,” but also “to do” and “to learn to do.” Osborne (1997) claimed clearly that “to learn” is different from “to do.” The French philosopher Bergson also considered that thinking and acting are different and complementary. For him, a goal of educating the young was

‘Penser comme un homme d’action. Agir comme un homme de pensée.’ (quoted by Renaud-Coulon and Syrieix, 1999)

With this background, the tool elaborated to describe labwork (Millar, Le Maréchal, & Tiberghien, 1999) and the different case studies (23 overall) demonstrated that the objectives

1 To think as a man of action. To do as a man of thought.
of labwork are numerous. The foremost identified problem was that embracing too many objectives in one session leads to failure. As a remediation, we propose to develop targeted labwork (Séré, 1998), suggesting that a limited number of objectives adapted to the situation should be selected. At the same time as the need to limit the number of objectives was demonstrated, the scope of objectives was widened. In this paper, we have examined various possible labwork objectives and the related research that needs to be undertaken at the present time. This is done using the classical categories of conceptual/procedural/epistemological objectives, that are still relevant. They are presented in the following order:

**Conceptual**

The first part is based on numerous studies on the conceptual acquirements established through labwork. A long lasting and often worded problem is teachers’ disappointment concerning (strong) expectations of conceptual learning. The different roles assigned to theoretical knowledge during labwork should not be considered as similar: verify, establish, discover, and utilize. This is a first type of research question to be addressed in the future: To identify which of these roles involve conceptual learning.

**Epistemological**

The aim of the second part is to make clear that, when working with apparatus and objects, students acquire an intuitive insight into the use of theory, the development of theoretical knowledge, the choice of data, the respective roles of measurement/observation. We show that, in this sense, labwork may be considered as an opportunity for placing the philosophy of science in its proper context. The key research question is now to elicit how each student performs successive tasks building gradually his/her image and his/her philosophy of science. Knowing that the same student works or has worked in biology, chemistry, physics, and mathematics, the question is to elicit how the gradual contribution of labwork in different domains converges or diverges with the students’ images of science.

**Procedural**

In the third part, some results concerning the role of processes in labwork will be recalled. Our work sheds light mainly on these investigative methods, procedures, and skills implemented in experiments, claimed to be important objectives of labwork. At the school level under study, they cannot be “rediscovered” by students. The key question is to identify what remains conscious, what is learnt as a process, and how an awareness of processes helps students to decide, plan, design, and realize experiments on their own. The link between procedural knowledge and autonomy must continue to be under question. This would allow a renewed view of the following question: Is it possible to make students, at this age, “mimic” the researchers’ activity? Though we did not address the problem of the social relationships in a group of students, considering procedures as tools of decision, could influence research questions on this topic.

**PART 1: CONCEPTUAL OBJECTIVES**

The two related goals of labwork are

- to learn scientific theories from the world of phenomena and
- to use theoretical knowledge in investigative tasks.
Thanks to the survey “Teachers’ objectives for labwork in Europe” (Welzel et al., 1998), it has been established, once again (Séré, Journeaux, & Winther, 1997), that teachers expect labwork to teach conceptual knowledge. The most highly ranked objectives have been put together under the wording “to link theory and practice.” This global wording, as well as the most frequent comments, implies teachers expect that practice is able to help teach theory. We claim that there is a reverse aspect: theory is a powerful tool for practice. This second aspect will be examined below after the classical one which somehow can be worded as: practice is often considered as “serving” theory.

**Practice “Serving” Theory**

The idea of practice serving theory, or more precisely, theory learning, pinpoints lots of pieces of research in which activities involving models, theories, and concepts are carried out in a laboratory with objects and hardware (Buty, in press; Hücke & Fischer, in press; Kariotoglou, in press). However, these activities are seldom specific to the presence of hardware. Intellectual processes and conceptual changes, passing from the world of objects to the world of models, are described. Frequently, the corresponding observations provide little information on the role of practice. As such, they sometimes fail to further research on labwork, whatever their global value. Consequently, there are few studies which compare learning conceptual knowledge with/without apparatus, with/without an experiment to look at, and with/without direct perceptions. Some years ago, a study compared conceptual learning from a lecture, from a demonstration, and from an experiment (Maury, Betbeder, & Hulin, 1983). The superiority of the lecture was demonstrated. More studies of this type need to be carried out.

**Theory “Serving” Practice**

The wording “to link theory and practice” is understood as “theory may help to learn to do.” This suggests that in numerous situations, conceptual knowledge is necessary from the beginning of an experiment at school, even during the first step of observing and understanding what the objects are. The “world of objects and observable things” (Bécu-Robinault, in press) sometimes has no intuitive significance in itself. If students are not familiar with the objects, they sometimes have to draw upon sophisticated previous knowledge to understand what to perceive, and what to do with the objects, what to measure, and what to model with them. The expression “intellectually constructed things and events” is used by several authors (Jenkins, 1979). Box 1 illustrates that it is not always possible to separate the world of ideas and the world of objects when representing the intellectual activities of modelling, especially at the school level. Firstly, it shows a situation where the observable object is directly understood and for which direct perceptions are interpretable. Secondly, it shows another situation in which it is necessary to draw upon knowledge about properties of metal, circuits, needle power, batteries, etc. just to understand what to do and before any attempt to learn anything more in electrostatics.

Akin to what Piaget (1972) described concerning the building of an object for children, in numerous situations students at this age have to use objects which demand an initial conceptual building before undertaking the required cognitive task.

Consequently, there is, drawing upon theoretical knowledge, much to learn from the first step of labwork using objects. Presently, this step is frequently neglected. Students accept passively to use such and such device and do not try to understand why such and such a choice has been made. Teachers have the habit of not focussing on the fact that, for instance, a measurement device is a “theory made object” (Hacking, 1983). It seems
that current common practice neglects the first phase in which theory is used and helps to understand practice, to focus on the following phases during which practice is supposed to teach theory, because theory has to be established or verified.

Box 2 illustrates this point of view. It summarizes two labsheets which impose a theory-laden “world of objects.”

It has been observed in the second case (physics) that students, although experienced in geometrical optics and well able to fulfil the task with the correct light source, were puzzled by an unforeseen event, namely producing the image of the filament of the bubble on the screen. They were also unable to make a slit, a punctual source, a parallel/divergent/convergent beam, let alone to make choices by themselves for a given experiment. Similarly, in the first case (biology), after the corresponding session, students are likely to be unable, later on, to justify the use of such and such a chemical and of a certain UV source. In both cases, the conceptual learning is poor and cannot be said successful.

In all these situations, preliminary theoretical knowledge is used, not questioned. When it is time to “do it again,” the student’s mind should be able to draw on pieces of knowledge to evaluate orders of magnitude, to make predictions, and to design experiments. When initiative and decisions are required, theory “serves” practice and helps “to do”. Further studies would be welcome, which would address the use of theory, and the effectiveness regarding an improved link between use and availability in students’ minds.

**Fine Descriptions of Students’ Thinking During Labwork are Necessary**

A first step in research should now be to describe what happens during labwork as exhaustively as possible. This was the idea of the “Map” developed by Millar, Le Maréchal,
The map was based on the assumption that what is expected by teachers is not always achieved by students. It distinguishes what students are intended to do/learn, and what students really do/learn. Here “to do” means “to do with mind” (comparing, establishing links, conceiving, etc.) as well as with hands. Effectiveness is defined as how well the aim coincides with what is realized. (Psillos, Niedderer, & Séré, 1998)

In this context, a case study attempted to compare what is expected with what is achieved by students. This study gives a fine description of students’ intellectual activity during plain, “stereotypical” physics labwork, where students are guided and all the hardware is available (Beney & Séré, 2001; Séré & Beney, 1997). The discrepancy between expectations and reality has been characterized: students “translate” for themselves the different tasks assigned in the labsheet. They frequently define successive goals and subgoals which differ from the steps imagined by teachers. Thus the task is “split” into small chunks. To develop these goals and to elaborate criteria to decide when to go ahead, they use very spontaneous rules which have different origins, for instance spontaneous representations, or rough recall of previous teaching, or even common sense, and finally little physics. The outcome of this study, and of many other ones, illustrates the weak use of concepts and theory during the session. The dependency upon guidance suggests the need for similar observations on students and tutors to make clear the use of theoretical knowledge during labwork and to devise guidance which would increase it.

**Conclusion: The Multiple Use of Theory**

In most of the experiments commonly found at the school level we studied, conceptual theoretical knowledge is present at every step. We have just seen that it is often illusory to interpret them as if the world of objects/events/observations was separated from the world of concepts and models. Unless the experiments are intentionally designed to obtain such a

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**BIOLOGY: Analysis of fluorescent labelled DNA.**
The manipulation itself involves observing samples under UV light and interpreting the obtained sequences of peaks. The characterisation of DNA demands sophisticated techniques and knowledge of various chemicals. In the labsheets, the use of the following chemicals is explained prior to the manipulation itself: agarose gel, ethidiumbromide, polymerases, dNTP, plasmid, restrictionenzyme Eco R1, bromophenolblue, Xyleneglycol, Glycerine, etc. One page and half is necessary to explain the ‘principle of the method’.

**PHYSICS: Geometrical optics**
The light source is available. The following choices have already been made: the size of the bubble, the use or not of a condenser, the shape and size of the diaphragm (hole, slit, shape of a letter), the direction of the diaphragm (slit parallel to the edge of the prism, for instance). Students are supposed to study laws of geometrical optics by observing the light rays AFTER the source.

**Two laboratory experiments at University level**
- **BIOLOGY** [Tiberghien and al. 1998]
- **PHYSICS** [TP DEUG University Paris XL 1997]

An intellectual effort is needed to build the objects to be manipulated. Often, the phase identifying the objects is passive and does not give the opportunity to learn what would be necessary to ‘do it again’

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2 In this study, concepts and results have been borrowed from cognitive psychology applied to action.
separation, the two worlds are entangled. This explains to a certain extent why conceptual learning is not an automatic outcome of labwork.

In our work, several studies stress the effectiveness of learning theories by utilizing them. This suggests to question the roles of theoretical knowledge in labwork, in the future, through clear distinctions between them. We suggest to distinguish letting students find or establish the proper theory, establishing and comparing more than one model for the same observations (software modelling is one of the most efficient methods (Sander et al., 2002)), providing the theory to be used (for familiarity), verifying a piece of theory, using it in simulations, and so forth. However, in each case, detours from the use of theory are possible. Therefore further effort is needed to conceive situations and pedagogical strategies which force students to use pieces of theory through appropriate questions. Empirical data have to be collected to describe in-depth how students manage and think in such situations.

PART 2: EPISTEMOLOGICAL OBJECTIVES
Each Session of Labwork is in Itself a Representation of a Paradigm of Science

In this part, we present a few results from surveys based on the assumption that students’ images of science relate to labwork through a twofold meaning. Firstly, an hypothesis of the LSE project was that what students do is influenced by what students know of the practice of science and of scientists’ activity: the importance granted to data (Lubben & Millar, 1996; Séré, Journeaux, & Larcher, 1992), the use of conceptual learning, the representation they have of dispersion when measurements are not reproducible, the faith in determinism (Séré, 1992), the acceptance of probabilistic reasoning; all these elements intervene in a largely unconscious way in students’ practice, decisions, and judgements during labwork. The second hypothesis is that this practice itself participates in the progressive shaping of students’ images of science.

In view of surveys and direct observations on students, we are led to question whether teaching epistemology is possible during labwork.

The Outcomes of Previous Surveys on Students’ and Teachers’ Images of Science

Several surveys have been carried out on the theme “Images of Science” during the last decade, the respondents being students or teachers (Désautels & Larochelle, 1998). Irrespective of the questions presenting a context or not, the knowledge in play is either from everyday life, or from science. By and large, they tend to extract ways of thinking from written responses, and to characterize each individual, student or teacher, by a personal epistemology supposedly giving an account of their reactions underlying their answers (Porlan, Rivero, & Martin del Pozo, 1998). Sometimes, there is poor consistency between the results. Authors sometimes recognize that the results support the need to refine hypotheses and questions (Koulaidis & Ogborn, 1989).

It appears that, in addition to “students” images of science” and “teachers” images of science,” we should also consider the images that researchers in science education have in mind. During the last few years, positivism became old-fashioned, whereas constructivism and socio-constructivism became more and more fashionable until a certain decline occurred (Solomon, 1994). Furthermore, it must be noted that there is no agreement among specialists about the “correct” view of science, the “proper” and supposed unique philosophy of science. It must also be noted that such and such an attitude is fruitful in such and such a domain
or subdomain of science. For instance, physicists tend to hold realistic views when they talk of “particles” as objects. This attitude ensures effectiveness. Similarly there is not one experimental approach which would be valuable in every domain, and which supposedly would lead to success, as is imagined by students lured by improper clear-cut descriptions.

So a receivable claim is that researchers’ images pinpoint the hypotheses of surveys and, by shaping the questions and the interpretations of answers, limit the credibility of such surveys. It now seems that the epistemology of the disciplines taught must be as clear as possible. However, clarity in this domain is problematic for scientists themselves, as shown in Box 3. This now seems to be an essential condition to avoid fruitless repetition in research.

The Surveys “Images of Science” in the LSE Project

Within the frame of the LSE project, we developed two types of questions in the same questionnaire and proposed to the same respondents, in order to allow comparisons:

a. questions within disciplinary contexts and
b. questions without specific contexts.

The results of the survey are reported in (Leach et al., 1998; Leach et al., 2000; Séré, 1998; Séré et al., 2001). We will address only this fundamental question: To what extent do respondents remain consistent from one question to the next in terms of the underlying epistemology? In other words, do respondents draw upon a given epistemology when they answer survey questions? If not, what do they draw on to answer?

The first survey3 presented a mix of open/closed questions; the respondents included students studying science disciplines in academic streams at both teaching levels (368) and teachers (106) as well. The main themes of the questions were the following: data processing in various cases of spread measurements, an experiment at school exhibiting discrepancies compared to the theoretical knowledge to be taught, and different conclusions from the same

3 This survey has been organized in two countries only and not intended to compare between countries.
The core idea of the survey was to establish a list of categories which could be used for all the questions, closed or open. In this paper we give no definitions of these categories. Each is labelled by one word: Data, Values, Statistics, etc. We just want to point out that most of them have both an ontological and an epistemological dimension, with the following meanings:

*From an ontological point of view*

Some students seem to see scientific knowledge as an exact copy of the physical world. Another group of students is conscious of a certain distance between mental models and reality.

*From an epistemological point of view*

Students see knowledge as very closely linked to data (observations and measurements), which it should match as closely as possible. Others view scientific work as an intellectual activity, the purpose of which is the explanation of reality which goes beyond the data itself.

We named the extreme ontological tendencies “identity of the real world with its scientific modelling/distance of the real world from its scientific modelling.” The two extreme epistemological tendencies are primacy of data/primacy of theory.

Box 4 shows the ontological and epistemological dimensions of eight of the categories. They share common characteristics when in the same quadrant of the plane. This is the case, for instance, for the categories Uncertainty, Deviation, and Range, in the upper-left quadrant of the plane.

So a respondent’s answer can be categorized and “situated” on plane Epistemology–Ontology. Consequently, if an individual’s reasoning patterns were stable and consistent over a range of contexts, any respondent could be “situated” on the plane Epistemology–Ontology. But examples of inconsistency are numerous. For instance, there were four opportunities where statistical reasoning was relevant. Overall, 49% used statistics in their answer once during the four possible occasions. But none of them did the same every time. Another example is that, in similar situations, the trend for students, when the situation becomes more complex, is to shift to the category Values (emphasis put on each measurement considered by itself, and not as one among others). Poor correlation is found between the categories of the same quadrant. All this is a characterization of students and teachers’ attitudes when they have to solve a contextualized problem involving data processing and mutual links between data and theory. One of the conclusions is that it’s not valid to attribute unique philosophical positions to individuals.

Another survey produced converging results to the same question: The British team carried out a survey for the same type of students (both teaching levels). The sample comprised 731 students from five countries(Leach et al., 2000). To search the range of types of reasoning used by students, it was possible to group reasoning in three large categories (in agreement with the preceding ones):

*Data focus reasoning:* When students view scientific knowledge as descriptions of the material world, and they think that differences of interpretation can be resolved by collecting enough data.

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4 Again this survey was not designed to compare results between countries, but to identify types of reasoning at the population level.
**Knowledge and data-related reasoning**: When the students’ view is that what scientists believe and what they do are related.

**Radical relativist reasoning**: Where the process of drawing conclusions is viewed as inherently problematic. In this view it is open to every individual to believe what they want, nothing can be said to be right or wrong.

These groups of reasoning, larger than in the preceding survey, were relevant for contextualized as well as general questions. The results are very similar, in the sense that the consistency is poor. An example is given in Box 5.

Both types of results cast doubt on absolute percentages of the use of such and such a type of reasoning or philosophical attitude.

**Different Solutions to Reach Epistemological Objectives**

It is not a surprise that many students do not learn what counts as appropriate scientific reasoning as a result of current teaching strategies. If this is seen as an important curricular goal for science education, then explicit teaching about the various relationships that can exist between theory and data in different situations should be required. A solution is to teach directly different types of models. This has been done in physics where models can be theoretical, simulated, black box, behaviour models (Guillon & Séré, 2002). An alternative solution is “learning by doing.” This was tested during fieldwork in earth sciences.
The students themselves practised geological mapping, with the obligation of finding results not previously known by the tutors guiding them. They acquired a better feeling of the respective role of theory and experiment, and some of them were able to drop a relativist view and shift to a theory and data reasoning:

> It's the first time I've ever realized that I'm actually as right as the next person. There's no-one else on there who knows any more than I know.

In fact any labwork session may be exploited, even though it may not be open-ended and very "stereotypical." It is possible to consider each one as a representation of a paradigm of science. This point of view would be the basis of specific comments from the tutor, in order to make students conscious of the respective roles of theory and data in each situation, to have access to a range of different kinds of epistemological reasoning and use them appropriately according to the context. With this aim, the questionnaires we developed could be adapted to each situation. This is an open field of research: to imagine situations especially adapted to shed light on a given role of theory in experimentation, and to develop teachers' training for this type of activity.

### Conclusion: Labwork Sessions are the Right Place to Use and Teach Epistemology

The numerous studies traditionally named "Images of science" constitute a capital which is now acquired. It is no longer relevant to repeat such research, based on the hypothesis
that each individual holds a general view of science, applicable to numerous contexts. The corresponding questions are available to suggest adaptations to certain situations of epistemological interest, because they characterize different aspects of scientific attitudes. A short list is for instance to recognize the need of a theoretical basis for a certain experiment, the influence of research questions on the type of data processing, the influence of the choice of the measuring device on the expected results, and so forth.

Much has to be done to favor a shift from a false, flawed, wrongly homogeneous image of science as it exists in several textbooks (Bandiera, 2002), to a finer analysis of the links between theory and data adapted to different contexts. It is time to recognize that there is no expert reference in philosophy of science. It is time to recognize the variety of links theory-data. This may be put into operation at least in two ways. A first possibility is to favor the development of students’ images of science through several disciplines in a collaborative way. A second step is to help teachers to be conscious of their own epistemology and ontology in their own domain of research, and to observe how it contributes to stimulating teaching. The effectiveness of labwork guidance, based on this consciousness, is open to question.

PART 3: PROCEDURAL OBJECTIVES

Awareness of Procedures, Know-How, and Approaches is the Key to Students’ Autonomy

At the academic level under study, there is a large range of procedures in play during labwork. The teachers planning each session put them into operation, but the reasons for choosing them is seldom presented directly in labsheets. More frequently, labsheets split the task into punctual steps. Students tend to be “data driven” (Haller, Welzel, & Von Aufschnaiter, 2002) and succeed in the assigned task with a poor understanding of the procedures. Unfortunately, learning by doing is seldom effective. If teachers and students are not aware of the importance of procedures, and do not strive to identify them in a given experiment, learning fails.

We will draw on a number of case-studies conducted during the LSE project, to illustrate the variety of procedures, know-how, approaches, and skills which are in play during existing labwork sessions.

Measurement Processes

To move from performing and observing a phenomenon, to achieving measurements, generally requires major changes to and adaptation of the experiment. Examples are numerous in biology (taking of tissues may change a living body, interaction between chemicals and the organism to be studied may modify it, etc.), in chemistry (the body under study must be modified, dissolved, buffered, coloured, heated, etc.), in physics (the signal must be transformed into an electrical signal adapted to a given receptor, for instance). Furthermore transformations of the basic experiment are necessary to obtain accuracy and precision (e.g. when a measurement is done by difference). There is a sort of negotiation between the experiment itself exhibiting a phenomenon, and the possibilities of the measuring instrument. Very often, at school, the experiment to be carried out is presented fully set-up, in order to take measurements reasonably precisely and as quickly as possible. The reason is that measuring is time-consuming and judged as not interesting. Thus students do not have the opportunity to become aware of the negotiation evoked above. They do not memorize the chosen procedures. Then these procedures do not constitute resources which can be drawn upon when designing experiments and taking decisions in the future. From this point of
view, it would be useful to transform the labsheets in order to make students conscious of the adaptation of the experiment to the constraints of measurement.

Data Processing

There are different types of data analysis according to domains and specific aims. Quite often, students think that data analysis is not part of the labwork session: they say that it can be done at home, using routine algorithms (Haller, Welzel, & Von Aufschnaiter, 2002). Similarly, it has been observed that teachers do not value this part of teaching, because they do not recognize it as knowledge essential to the design of experiments (Lewis, 2002) and they are not conscious that choices are seldom a routine. On the other hand, it is an illusion to attempt to teach practical skills, and particularly data analysis, just by itself out of context.

Box 6 summarizes two tasks in genetics and in physics. One is devoted to data analysis only, with no data collection. The other is devoted to the use of graphs. It appears that students are currently reluctant to focus on data analysis during labwork. Most teachers think the same (Séré, Journeaux, & Winther, 1998).

Computer Science Know-How

Three case-studies from the LSE project, (Beaufils, 1998; Bisdikian & Psillos, 2002; Sander, Niedderer, & Schecker, 2002), highlight the difficulties encountered by students

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<th>BIOCHEMISTRY: 'dry practicals'</th>
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<td>• Students were presented with data on the kinetics of an enzyme. They were instructed to undertake various procedures to determine significant kinetic constants, and to interpret them in terms of the Michaelis-Menten model.</td>
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<tr>
<td>• Students were observed and given a written questionnaire to identify what they had understood about the relationship between the model of enzyme kinetics and data on particular enzyme reaction rates.</td>
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<tr>
<td>• The results concern the way students processed the spread of measurements, took into account the thermodynamic conditions to explain dispersion, considered the model as applying to any enzyme or not, etc.</td>
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<td>Such an activity, without any data collection, can teach much about data processing, thanks to a particular context.</td>
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<td>[Leach, 2002]</td>
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<th>PHYSICS: using software to relate graphs and experiment</th>
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<td>• Real-time graphs are displayed on the screen as the lab experiment demonstrating heat conduction and changes of states proceeds. Thus students witness the consequences of their own actions, when manipulating the experimental parameters, directly on the graphical representation of these parameters.</td>
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<td>• By observing students, we are able to analyse to what extent students read, interpret and compare graphs in order to extract relations between physical variables, and how they construct graphical representations to describe a given evolution in the experiment, etc.</td>
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<tr>
<td>• Finally, this skill allows students to predict events by interpreting graphs and planning experimental activities.</td>
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<td>[Bisdikian and Psillos, 2002]</td>
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Two examples of laboratory sessions with procedural objectives

BOX 6
in using a computer efficiently during labwork. They show that some tasks, involving a computer, have no meaning, if some know-how is not taught. If teachers consider computer skills lie outside the scope of the topic and is a routine task, the only avenue open to them is to split it into punctual steps and guide students with a recipe: “click once, enter the data with three digits, click twice, etc.” The loss of comprehension of these operations leads to a failure in understanding the issue. A minimum amount of computer familiarity needs to be taught to provide an overall view of the task and allow room for initiative when analyzing data. This minimum has seldom been analyzed properly. Corresponding studies will have to be constantly updated in view of the rapidly advancing techniques.

Investigative Pathways and Experimental Design

At the school level we studied, we assume that the students should be mature enough to be able to make decisions, and to choose how to investigate and design experiments. This is a wish of the students, as they say during interviews (Haller, Welzel, & Von Aufschnaiter, 2002):

I would prefer to investigate new own questions and not things which are so predetermined [during labwork] what I certainly miss, is that there is no possibility to build the experiment in my own way up

This sort of activity can be proposed during open-ended labwork. Nevertheless such sessions are not always successful. They can be successful if students have been given “tools,” namely a variety of procedures among which they have to choose and the resources needed to conceive, imagine, and design experiments. In physics, the examples of procedures are numerous, often aiming to achieve accuracy and precision. Some of them are used in biology and chemistry as well. In these two domains, the proper use of glassware, the techniques of observation at a microscopic level, and the choice of the proper level of observation (system, organ, cell, molecule) are especially important. In biology a tricky procedure is the design of comparison groups (Coquidé, Bourgeois-Victor, & Desbeaux-Salvia, 1999) where the variability of living beings intervenes.

To meet the desire of autonomy voiced by students and felt by teachers, it can be surmised that one of the problems is the teaching of procedures. This supposes giving up the idea that procedures have just to be experienced to be learnt.

Conclusion: Procedures and Autonomy

Our conclusions are based on the three different facts coming from observations of students and teachers. Firstly, students persist in expecting conceptual learning and only conceptual learning during labwork. They are not accustomed to grasping procedural knowledge during labwork. Teachers hold similar views. Secondly, learning only by doing is very inefficient in acquiring procedural knowledge. It is difficult to “do it again” if it has just been done once, with no specific emphasis. Thirdly, it is impossible to teach procedures separately. It requires a context (N’Tombela, 1999).

Now if we turn to consider the practice of researchers (Beney, 1998), we see that there is a big difference between researchers and students: the former hold readily available procedures; the latter are deprived of procedures and are continuously impeded by corresponding obstacles. Students have no “thread” like Ariane in the maze as opposed to “experts” who
do have “threads,” namely the knowledge of a variety of procedures. This is consistent with the claim that there is some illusion in aiming to make students mimic researchers’ activity (N’Tombela, 1999) and professionals’ activity (Molyneux-Hodgson, Sutherland, & Butterfield, 1999). The latter, concluding observations on students carrying out activities in a context pretending to be professional, state the following:

The role of the [professional] work contexts could be considered as “window dressing”

What we propose now as research hypothesis is to consider that procedural knowledge constitutes “tools” for autonomy. Its place has to be studied in open-ended labwork and projects, which are considered traditionally as the main strategies to promote autonomy. But they are time-consuming and remain exceptional. The main directions of research to address now is to prepare students for autonomy, by changing greatly the place given to procedures, measurement, data analysis, and more generally investigative methods. It is necessary to give to theses procedures a specific role, not as a pretext to teach conceptual knowledge, but as valuable objectives. This is in teachers’ hands, who could adopt a new way of exploiting traditional sessions of labwork. But this will not arise without careful observations of students having opportunities of initiative during standard labwork.

CONCLUSION

The work of the researchers involved in the project Labwork in Science Education, leads to the conclusion that there are numerous potential objectives which can be aimed for in a laboratory. “To do” and “to learn to do” must be taken as seriously as “to understand” and “to learn,” as mentioned in the introduction. The view of labwork serving conceptual knowledge exclusively must be abandoned. All types of objectives are relevant to constitute the “disciplinary matrix” that Kuhn (1962) identified in scientists’ mind. In this view, the difficulty is the number of possible objectives. For a given situation, labwork conceivers should now consider that a significant part of their work is to make conscious choices to put aside some traditional objectives, and to put emphasis on new ones. The corresponding lines of research concern new roles given to conceptual knowledge, new importance given to procedures when promoting autonomy, attention paid to the progressive shaping of students’ images of science. The pinpointing hypotheses are threefold: students do not just grasp ideas of science in a random way, by themselves. The selection of procedures, of help in situations promoting initiative, has to be done carefully. Specific conceptual knowledge is necessary to understand the measuring instruments, to understand why such a procedure allows measurement and precision, to understand the choice of a given data analysis method. Ways to elicit and make clear to students the role of conceptual knowledge during all the phases of the experimental session, have to be imagined.

Research perspectives in terms of observations of students, are numerous. As highlighted, empirical data have to be collected during labwork sessions with research questions concerning each type of objectives classically recognized, for the sake of communication with teachers and labwork tutors. This is in line with one of the recommendations of the LSE consortium: research must now result in labwork tutors’ training. The renewal of interest and effectiveness of labwork is in their hands, by means of the guidance they provide. Experiments do not speak by themselves. Tutors must be conscious of the target of each session and their interventions must be colored accordingly. The research prospects are mainly in the domain of written guidance and teacher training.
In order to address the problem of the effectiveness of labwork, it was decided to produce a new formulation of objectives to meet new needs in Science Education; study and elicit the general advantages of specific aspects of national education systems; review the key competencies promoted through labwork.

The tasks and outcomes were the following:

A GRID OF ANALYSIS OF LABWORK SHEETS. “The map of variety of labwork” was developed in order to analyze labwork sheets from across Europe, showing similarities and differences.

A survey at European level, named VARIETY OF LABWORK IN EUROPE could describe the practice in each country, particularly teachers’ practice. The survey achieved a comparison of different educational systems as well.

A second survey was carried out to elicit STUDENTS’ AND TEACHERS’ IMAGES OF SCIENCE as related to labwork.

A third survey studied TEACHERS’ OBJECTIVES FOR LABWORK in Europe.

Twenty three case-studies in five countries were carried out on specific issues, to generate illustrative material and to serve as a basis for the development of recommendations for effectiveness.

They illustrate the diverse organizational structures for labwork and the possible objectives in the following contexts:

Typical guided labwork;
Sessions including new technologies;
Open-ended labwork;
Sessions aimed to focus on selected phases of an experimental approach.

The project produced recommendations summarized as follows: In order to avoid the frequent mismatch between teachers’ objectives and what is achieved, done and thought by students, each labwork session should be reasonably ambitious and targeted, the strategy being a clear orientation towards certain selected objectives. The notion of target could replace the notion of objectives, acknowledging the frequent overlapping of conceptual/procedural/epistemological objectives at the academic level considered. Labwork should have a structure made clear to students, supported by a given strategy, and organized within a coherent long-term program with varied types of labwork.

The project resulted in a final report which has been accepted and published by the European Commission under the title of the project, and 10 working papers, expanding data and results.

**Final Report**


**Working Papers Available on**

http://www.univ-lyon2.fr/GRIC-COAST/.

**Research Papers**


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Chapters in Books


PhD Dissertations


I thank the 38 members of the LSE project. Among them were 11 PhD students. We worked hard together and we had very stimulating meetings and discussions during nearly 3 years. As the co-ordinator of the project, I am especially indebted to the group leaders who shared the responsibilities, the various tasks of this ambitious project, participated in the management and in all the reports required by the European Commission: John Leach (University of Leeds, UK), Hans Niedderer (University of Bremen, Germany), Albert Christian Paulsen (Royal School of Education, Denmark), Dimitris Psillos (University of Thessaloniki, Greece), Andrée Tiberghien (Université Lyon 2, France), and Matilde Vicentini (Universita di Roma La Sapienza, Italy). I also thank my own group (DidaScO, University Paris Sud XI, France) for help, and the department Didactica de las Ciencias Experimentales (University of Granada, Spain) for participation.

It was during the years 1996–98 that we took seriously the aim of building a scientific community and to collaborate closely with all of us. Then came two or three team collaborations, wherein we had to terminate certain analyses, defend theses, organise meetings as well as write (see bibliography for the book edited by D. Psillos and H. Niedderer, the proceedings edited by J. Leach and A. Paulsen, and a number of juried research papers). So this paper, written 2 years after the official end of the project, thrice from a number of contacts I kept as an ex-coordinator. It goes beyond the common
work achieved during the duration of the project. I am grateful for the private discussions that helped to produce it.

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