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LABWORK IN SCIENCE EDUCATION

* WORKING PAPER 1 *

A MAP OF THE VARIETY OF LABWORK

Robin Millar, Jean-François Le Maréchal and Christian Buty

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Contact Details: Prof. Robin Millar
Department of Educational Studies
The University of York
Heslington
York YO1 5DD
UK

Tel. +44 1904 433469
Fax. + 44 1904 434078
Email: rhm1@york.ac.uk

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The Partnership:

France - DidaSco Université Paris XI and INRP
Marie-Geneviève Séré (Co-ordinator and Group Leader), Daniel Beaufils, Michel Beney, Alain Guillon, Didier Pol, Nahim Salamé, Jean Winther

Denmark - FIFU, Regional Centre of research and promotion of Further education
Albert C. Paulsen (Group-leader, Royal Danish School of Educational Studies), Dorte Hammelev (Roskilde University), Helge Kudahl (FIFU)

France - COAST - GRIC Université Lyon 2
Andrée Tiberghien (Group Leader), Karine Beçu-Robinault, Christian Buty, Jean-François Le Maréchal, Laurent Veillard

Great Britain - LIS, The University of Leeds; The University of York; King's College, London
John Leach (Group Leader, The University of Leeds), the late Rosalind Driver (King's College), Jenny Lewis (The University of Leeds), Robin Millar (University of York), Jim Ryder (The University of Leeds)

Germany - Institut für Didaktik der Physik, University of Bremen; University of Dortmund
Hans Niedderer (Group Leader), Stefan non Aufschnaiter, Hans Fischer, Kerstin Haller, Lorenz Hucke, Florian Sander, Horst Schecker, Manuela Welzel

Greece - TESME, Aristotle University of Thessaloniki
Dimitris Psillos (Group Leader), A Basrbas, Garabet, Garo Bisdikian, Dimitris Evangelinos, Petros Kariotoglou, Koumaras, Anastasios Moholidis, Vasilis Tselfes

Italy - University of Rome 'La Sapienza'; University of Rome 3
Matilde Vicentini (Group Leader), Milena Bandiera, Francesco Dupré, Carlo Tarsitani, Eugenio Torracca

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A list of the full set of Working Papers from the project can be found at the end of this document. Further results from this work can be found on the Internet via the CORDIS site of the European Commission : http://www.cordis.lu/
The abstract of the project provided on this site is given on the next page.

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ABSTRACT: *'Labwork in Science Education '*

This project stems from a concern to recognise science education as an important component of a general education, not only for future scientists and engineers, but also for any future citizen in a European society which is increasingly dependent upon science and technology.

Research has focused upon the role of laboratory work ('labwork') in science teaching at the levels of **upper secondary school and the first two years of undergraduate study**, in physics, chemistry and biology. Various forms of labwork have been identified and investigated, including 'typical' activities in which pairs of students work on activities following precise instructions, open-ended project work in which students design and carry out empirical investigations, and the use of modern technologies for modelling, simulating and data processing.

The main objectives of the project were to clarify and differentiate learning objectives for labwork, and to conduct investigations yielding information that might be used in the design of labwork approaches that are as effective as possible in promoting student learning.

A survey was conducted to allow for better description of existing labwork practices in the countries involved. There are great variations from country to country in the time devoted to labwork, the assessment of students' performance in labwork and the equipment available. However, the forms of labwork activity used between countries are remarkably similar. In each country, the most frequent activity involves students following precise instructions in pairs or threes. A document has been produced describing the place of labwork in science education in each country.

A second survey was conducted to study the learning objectives attributed to labwork by teachers. There are some differences between countries in terms of the relative importance given to the teaching of laboratory skills. Motivation for science learning is not attributed particularly high status as an objective for labwork learning. In each country, the main goal for labwork teaching in the view of teachers surveyed concerns enabling students to form links 'between theory and practice'.

A third piece of survey work was conducted to investigate the images of science drawn upon by students during labwork, and the image of science conveyed to students by teachers during labwork. These surveys were based upon the hypothesis that epistemological and sociological ideas about science are prominent during labwork.

22 case studies were carried out in order to clarify the variety of knowledge, attitudes and competencies that can be promoted through labwork. The case studies focused upon both empirical labwork and labwork involving computer modelling and simulation. The work has resulted in an analysis of the **effectiveness of labwork**, leading to recommendations about policy. It is hoped that teachers and policy makers with responsibilities in science education generally, and labwork in particular, will find these useful in informing future practice with respect to possible objectives for labwork, links between objectives, methods of organisation of labwork and ways of observing and evaluating the effectiveness of labwork in promoting student learning.

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A map of the variety of labwork in Europe

Robin Millar, Jean-François Le Maréchal and Christian Buty

1 What do we mean by 'labwork'?

In almost all countries, science education, at some level[1], involves students and teachers working together in laboratories, or in the field. In this paper, the term 'labwork' will be used to refer to all the kinds of teaching and learning activities associated with teaching laboratories, or with practical work in other settings. This includes:

1. all those kinds of learning activities in science which involve students in doing, or watching someone else do, a practical task (whether inside a laboratory or somewhere else);
2. learning activities designed to prepare students for some specific aspect(s) of such practical tasks.

So labwork is a sub-set of science teaching/learning activities in general (Figure 1).

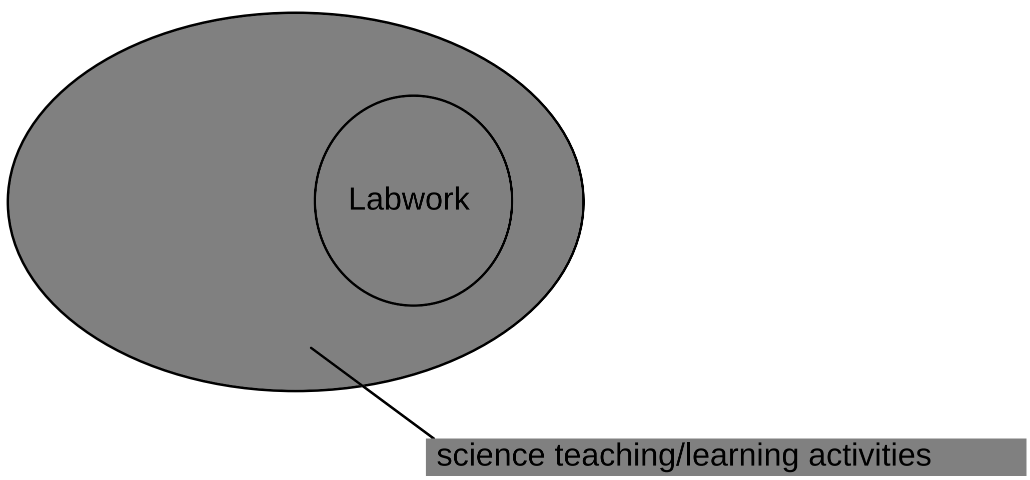

Figure 1 Labwork as a subset of science teaching/learning activities

The boundary between labwork and other science teaching/learning activities is not, however, as clear-cut as Figure 1 suggests and is, indeed, somewhat arbitrary. The first of the two categories above is clear enough; the difficulties arise with the second. The problem here is that almost all

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[1] In some countries, teaching laboratories are common in school science teaching, from an early age; in others, students are introduced to laboratory work at a later stage, though they may have observed teacher demonstrations in an earlier phase of their science education.

science teaching/learning activities can be seen as, in some sense, a preparation for carrying out, or observing, practical work. Some tasks are specifically designed as a preparation for practical work: an example might be a data analysis exercise designed to teach some important ideas about the handling of data from a practical task, or about error analysis. Tasks of this sort come unproblematically within the second category. But it is equally clear that a student's conceptual knowledge has a critical influence on their understanding of the purposes of a practical task, and so on their conduct of the task, and on their analysis and interpretation of any data collected. So teaching/learning activities which are entirely non-practical and are primarily focused on the development of students' conceptual understanding are also a preparation for any future practical task which involves these ideas and concepts. If these were also to be included within the category of 'labwork', however, then 'labwork' would simply expand to include all science teaching/learning activities, and so would cease to be useful as a term.

So a key factor in deciding whether or not to regard a particular task as 'labwork' is the <u>primary</u> purpose of the task: is it designed to teach ideas which are needed for specific practical tasks to be undertaken later, or to develop students' conceptual understanding generally? If the former, we will include it within the category of 'labwork'.

Despite the absence of a clear-cut line of demarcation, of the sort that Figure 1 might seem to imply, 'labwork' is widely recognised by science teachers and educators as a distinct (and distinctive) type of science teaching/learning activity. So, in continuing to use the term, we are not creating a novel category, but rather exploring the boundaries of a category which is already in widespread use and trying to define its characteristics more precisely.

2 The variety of labwork

Labwork in science education can take a very wide variety of forms. Labwork tasks have a range of learning objectives, and differ considerably in terms of what the student is expected to do - both with physical objects, and with ideas. If we want to raise questions about the effectiveness of labwork, or try to improve its effectiveness, then a 'map' of the varieties of labwork task may be useful. This will provide a description against which a judgement of effectiveness may be made. It may also help us to see new possibilities for the presentation of a particular labwork task; or it may alert us to characteristics of our use of labwork of which we would otherwise be unaware.

One way to develop such a classification of the varieties of labwork is to start from what we might call a 'typical laboratory exercise'. This is a teaching and learning activity in which a small group of students interacts with real materials and/or equipment, following detailed instructions from the teacher. Exercises of this kind are used in most countries at some level(s) of the education system. We can then identify other types of 'labwork' which diverge in different ways from the 'typical laboratory exercise':

- the students may not carry out the task themselves, but watch a teacher carrying it out;
- the students may obtain information not from real objects and materials, but from a video recording, a computer simulation, a CD-ROM, or even from a text-based account;

- full instructions may not be given but instead the students are required to make some decisions for themselves as to how to proceed;
- students may be asked to undertake only part of a task, for example, to propose a plan for carrying out an investigation, or to interpret some given data.

Each of these differs from a 'typical laboratory exercise' *in one respect*. This classification is summarised in Figure 2.

Figure 2 Varieties of labwork

3 Designing and evaluating labwork

Figure 2 provides a means of classifying examples of labwork into one of five main categories. Each category, however, still includes a very wide variety of types of teaching/learning activity. A 'map' will need to be more detailed if it is to be of help to researchers or teachers who are designing labwork for groups of students. To develop such a map, it is helpful to consider the stages involved in the design and evaluation of a labwork task, and the influences on each. A simple model of this process is set out in Figure 3:

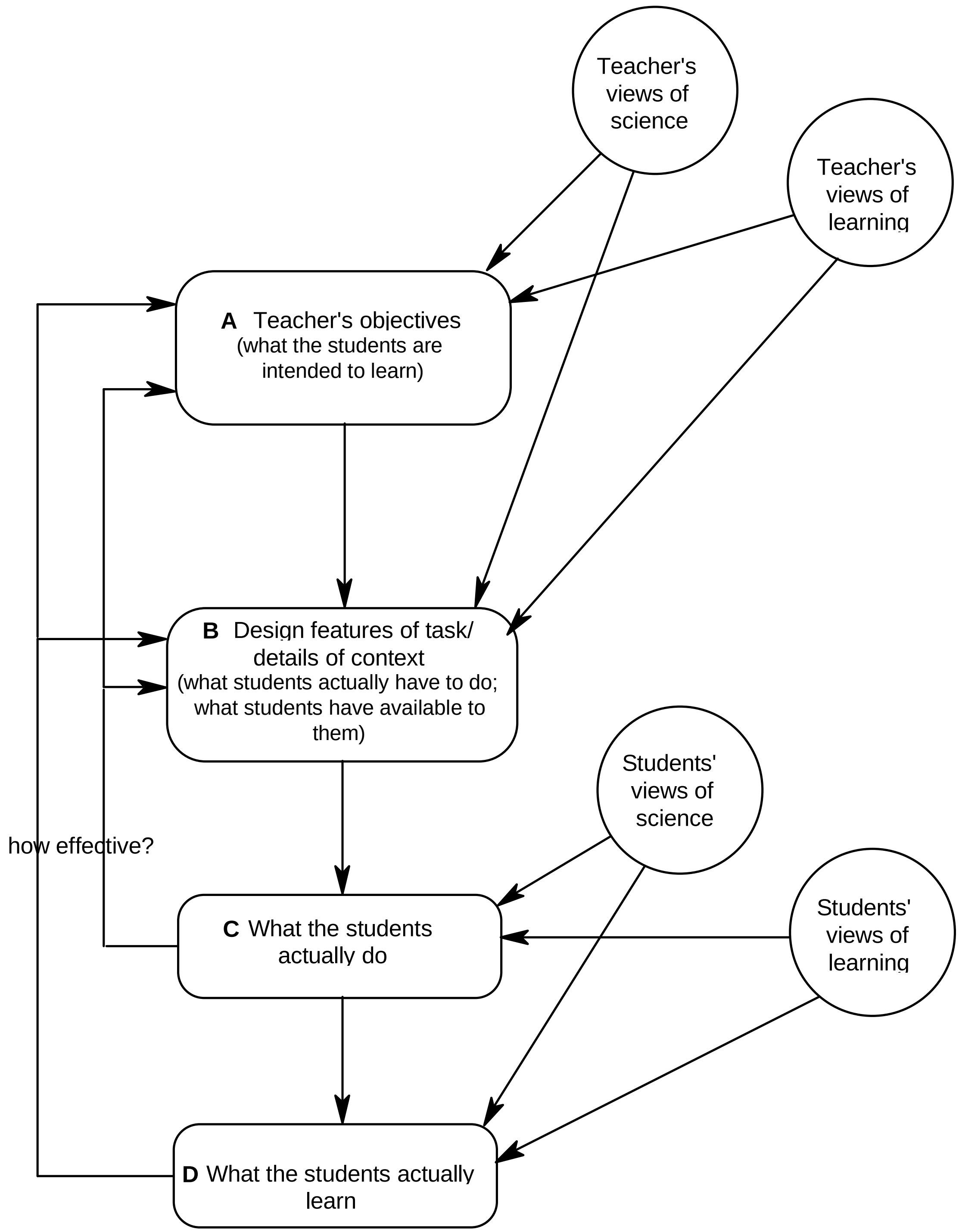

Figure 3 **Design and evaluation of a science teaching/learning task**

The design of a teaching/learning task might be thought to start with the learning objectives the teacher has in mind (Box A of Figure 3): what does he or she want the students to learn? This leads directly on to the design of the task which is to be used to achieve those objectives (Box B).

The choices made and the decisions taken in boxes A and B are influenced by many considerations, two of which are likely to be the teacher's view of science (of what is important to try to teach, of the nature of this knowledge, and so on) and the teacher's view of learning (ideas about how students learn). Some aspects of this background influence may be explicit, whilst others may be tacit.

In designing the teaching/learning task, the teacher intends that the students will do something when given the task. So the model in Figure 3 leads on to the question of what the students *actually* do when carrying out the task (Box C). This may be as the teacher intended, or it may differ from it in certain ways. For example, students may misunderstand the instructions and carry out actions which are not the ones the teacher had in mind. Or they may carry out the intended operations on objects, but not engage in the kind of thinking about these which the teacher intended. Finally, the process leads on to box D, where we ask what the students learned from carrying out the task. Like the teacher's decisions in planning the task, the students' actions and learning as they carry it out (Boxes C and D) are also influenced by many factors, two of which are their views of science (their interest in the subject matter, their understanding of the connections to other ideas, and so on) and their views of learning (ideas about how one learns the sorts of ideas involved).

The model set out in Figure 3 is also useful when we turn to the question of the effectiveness of particular labwork tasks. A first level of enquiry into effectiveness would ask the question: do the students actually do the things we wished them to do when we designed the task? This is about the relationship between C and B. It then leads on to the more difficult (from a researcher's perspective) question of the effectiveness of a task in promoting student learning (the relationship between D and A). If we are interested in effectiveness in this second sense, then we need to be realistic about what is possible. The possibility of demonstrating that learning has occurred will vary greatly from task to task, depending on the complexity of the learning intended. For example, it might be possible to obtain clear evidence of student learning about how to use an instrument or a laboratory procedure following a single labwork task. But it is unrealistic to expect significant (and observable) changes in a student's conceptual understanding to result from a single labwork task. On the other hand, it may be possible to reach a view, informed by research evidence, about the effectiveness of a labwork task in encouraging students to engage with conceptual ideas in the way the task designer intended (the relationship between C and B), and hence to make inferences about its value as a support for conceptual learning.

The feedback loops on the left-hand side of Figure 3 indicate the possible responses if we find that the relationship between boxes C and B, or between boxes D and A, are not as close as we would wish. This may lead us to modify aspects of the design of the task (Box B) whilst keeping the learning objectives (Box A) the same; or it may make us reconsider the learning objectives themselves.

The model of Figure 3 has implications for the task of classifying varieties of labwork

tasks. Any such classification will need to take account of the two major aspects associated with boxes A and B:

aspect A intended learning outcome (learning objective)
aspect B design features of task and of context

In the remainder of this paper, a 'map' (or taxonomy) of labwork tasks is proposed and discussed. This provides a means of describing in detail any given labwork task[2]. Appendix 1 summarises this 'map' in the form of a proforma which can be used to provide a profile of a labwork task.

4 A 'map' of 'labwork'

The 'map' of 'labwork' proposed below was developed at a relatively early stage of an international collaborative project, on Labwork in Science Education in Europe (LSE), as a tool for use within the project and perhaps beyond it. It has evolved during the project. The version set out in this paper was adopted as a working tool for use within the LSE project. Experience in using it within the project is likely to lead to further improvements and modifications to enhance its usefulness as a tool for research.

The 'map' consists of a series of main dimensions, some with sub-dimensions. These are:

A Intended learning outcome (learning objective)

B1 Design features of the task
- B1.1 What students are intended to do with objects and observables
- B1.2 What students are intended to do with ideas
- B1.3 Whether the task is observation- or ideas-driven
- B1.4 The degree of openness/closure of the task
- B1.5 The nature of student involvement in the task

B2 Context of the task
- B2.1 The duration of the task
- B2.2 The people with whom the student interacts whilst carrying out the task
- B2.3 The information sources available to the student
- B2.4 The type of apparatus involved

For each sub-dimension, a labwork task is characterised either by selecting the most appropriate descriptor (or descriptors) from a list, or by ticking a number of boxes in a table. The coding categories within each sub-dimension are not mutually exclusive. Many labwork tasks will be coded as matching several of the coding categories. The intention is not to provide a set of

[2] This discussion has introduced the idea of a 'labwork task'. This raises the issue of what is to count as a 'task'. Some laboratory exercises consist of a number of related tasks for students to complete: is each to be considered a separate 'labwork task', or the whole activity as a single 'task'? The best solution to this appears to be a pragmatic one, defining a 'labwork task' as an activity which the teacher (or researcher) involved regards as a reasonably self-contained unit of work for the students.

‘pigeon-holes’ for each sub-category, such that every task would fit neatly into one of these. Rather it is to provide a means of obtaining a characteristic ‘profile’ of each labwork task.

4.1 Dimension A: Intended learning outcome (learning objective)

A first dimension for classifying a labwork task is the intended learning outcome (or learning objective) which the teacher or the designer of the task has in mind in presenting the task.

Learning objectives divide into two main categories, associated with the learning of science content or of the processes of scientific enquiry. These can be further sub-divided as follows:

Content:

a to help students identify objects and phenomena and become familiar with them
b to help students learn a fact (or facts)
c to help students learn a concept
d to help students learn a relationship
e to help students learn a theory/model

Process:

f to help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus
g to help students learn how to carry out a standard procedure
h to help students learn how to plan an investigation to address a specific question or problem
i to help students learn how to process data
j to help students learn how to use data to support a conclusion
k to help students learn how to communicate the results of their work

In b, a 'fact' means a statement which can be readily agreed, such as that pure water boils at (or near to) 100^{o}C, or that common salt dissolves in water whilst chalk does not.
In d, a 'relationship' might be a pattern or regularity in the behaviour of a set of objects or substances, or an empirical law.

Some labwork tasks may have more than one of the above learning objectives. It is also unlikely that some (like k) would ever be the sole objective of a labwork task. In classifying a task by its learning objective(s), the focus should be on the most important objective or objectives, rather than identifying all the possible objectives.

4.2 Dimension B.1: Design features of task

A second, and independent, dimension for classifying labwork tasks is on the basis of aspect B of Figure 3: the design features of the task. This dimension can be divided into five separate sub-dimensions:

1. what students are intended to do with objects and observables
2. what students are expected to do with ideas
3. whether the task begins with observations and leads towards ideas, or begins from ideas which then influence what is to be observed

4 the extent to which the student is able (or is required) to make decisions and choices about how to carry out the task
5 the nature of student involvement in the task (are they actively involved, or observers?)

The first two of these are the most important ones - and the most difficult to sub-divide and categorise. The underlying model here is of labwork as a means of helping students to 'build bridges' between the domain of objects and observable things, and the domain of ideas. So we can think of a task in terms of what it intends that students will do with objects and with ideas. The third sub-dimension is about the relationship between the first and second ones; and the final two focus on the nature of the student's involvement in the task. Each of these will be considered in turn.

4.2.1 What students are intended to do with objects and observables

Most labwork tasks involve the student in manipulating and/or observing objects or materials. Some involve learning how to use an instrument, or procedure. The student may be intended to:

- use an observation or measuring instrument
  e.g. use a microscope to look at onion skin cells;
  use a cathode ray oscilloscope (CRO) to look at some signal waveforms;
  use a burette to deliver measured volumes of a liquid.

- use a laboratory device or arrangement
  e.g. set up distillation apparatus to separate two miscible liquids;
  use a dissecting kit/scalpel to remove a muscle from a chicken wing;
  set up a filter funnel to separate a solid from a liquid.

- use a laboratory procedure
  e.g. carry out a recrystallisation of a compound to produce a purer sample;
  set up a control for a biological investigation;
  follow a standard schedule for qualitative analysis of a sample of an unknown inorganic compound.

A different type of task is one which involves learning how to present an object so as to display certain features of it clearly. Here the student is intended to:

- present or display an object
  e.g. carry out a dissection of a biological specimen to display the main features of interest;
  display a collection of geological specimens to illustrate a particular feature.

Other tasks require the student to make something. This may be a physical object, or a material (e.g. a chemical substance), or an event:

- make an object
  e.g. make a microscope slide to display the cells of a given specimen;
  make an electric circuit from a given circuit diagram.

- make a material
  e.g. *synthesise a particular chemical substance.*

- make an event occur
  e.g. *tune an electric circuit containing a capacitor (C) and an inductor (L) to show resonance.*

The fourth, and perhaps the largest, category of labwork tasks is those which require the student to <u>observe</u> something. The observation may be of an object, or a material. The student may be intended to:

- observe an object
  e.g. *note and record the pattern of iron filings sprinkled around a bar magnet;*
  look at some fossil specimens;
  inspect some rock samples with a hand lens for evidence of volcanic origins.

- observe a material
  e.g. *note and record the shape of crystals of copper sulphate;*
  note and record the physical properties of a sample of polythene.

In other situations, the observation is better characterised as observation of an event. Here the student is required to:

- observe an event
  e.g. *record the manner in which an animal (an invertebrate, a fish) moves;*
  note what happens when a piece of sodium is placed in water;
  pass a ray of white light through a prism and note the spectrum produced;
  make observations of the germination and growth of a broad bean;
  note whether an object floats or sinks when placed in water.

Finally, the task may involve the observation of a physical quantity (or variable) associated with an object, or material, or event. Such an observation may be qualitative (e.g. an observation of colour), or semi-quantitative (noting if something is large, or small), or quantitative (i.e. a <u>measurement</u>). In these cases, the student is intended to:

- observe a quantity
  e.g. *measure the resistance of a piece of wire;*
  measure the volume of an acid solution needed to neutralise a given volume of an alkali solution;
  measure the density of a sample of a solid material;
  measure the length of a spring with different loads hanging from it;
  measure the melting point of a substance;
  observe the change in temperature of water in an insulated container over a period of time.

These categories are summarised in Table 1 below. Further information about the location of the work (inside or outside the lab) and about the origin of the data acquired by the students can be given by placing a tick in the appropriate column. In the case of the 'observe' categories, the data will usually come from the real world, but in some situations it may come from a video recording of a real event, or from a simulation on a computer or CD-ROM. Finally, the data may be presented in text form, with the focus of the activity on its analysis and interpretation. This is not, of course, true 'observation'. Also, in the case of the category 'observe a quantity', instead of a tick, the symbols Qt (quantitative); SQt (semi-quantitative) and Ql (qualitative) can be used to provide additional information about the nature of the data acquired.

What students are intended to do with objects and observables		**Location of work/origin of data acquired by students** **(tick as appropriate)**				
		from real world		from video	from computer or CD-ROM	from text
		inside laboratory	outside laboratory			
use	an observation or measuring instrument					
	a laboratory device or arrangement					
	a laboratory procedure					
present or display	an object					
make	an object					
	a material					
	an event occur					
observe	an object					
	a material					
	an event					
	a quantity					

Table 1 A classification of labwork tasks according to what students are intended to do with objects and observables

A few further comments are needed to clarify the meaning of the categories in Table 1 above. First, although all entries in the table are in the singular (an object, a material, etc.), this should also be taken to include the plural, for example, where a labwork task involves making several objects or materials, or observing more than one object, material, event, or quantity. Second, for many labwork tasks, more than one box in Table 1 will apply. For example, measuring a physical quantity necessarily involves 'using a measuring instrument'. The classification chosen should reflect the main intention of the task: to learn how to use the instrument, or to obtain a value for a quantity.

4.2.2 What students are intended to do with ideas

Labwork tasks do not only involve observation and/or manipulation of objects and materials. They also involve the students in using, applying, and perhaps extending, their ideas. That is, in addition to 'work with the hands', labwork also requires 'work with the head'. Indeed the centrality of labwork in science education lies in its power to bridge the two domains of observables and ideas. So a labwork task can also be classified according to what the students are intended to do with ideas.

Some labwork tasks simply require direct reporting of observations, though, of course, the selection of features to observe and record is inevitably influenced by the teacher's and/or student's purposes and understandings:

- report observation(s)
  e.g. describe in detail how a fish moves;
  describe the shape of crystals of a given substance.

Other labwork tasks require the student to identify a pattern, or regularity, in the behaviour of the objects or events observed:

- identify a pattern
  e.g. compare the measured IR spectrum of an organic compound to known IR spectra in order to identify it;
  note the different plant and animal species found at different levels of a seashore habitat.
  compare the outcome of a test for glucose on a sample of foodstuff with a previously observed positive test;
  note the regular changes in the appearance of the moon over a 29 day cycle;
  identify the objects and variables in an environment which are involved in some interactions of interest within that environment.

One particular type of 'pattern' which is common (and so worth keeping as a separate category) is a relationship between objects, or between physical quantities (variables). Students may be asked to:

- explore relation between objects
  e.g. note that a pinhole camera produces an inverted image on the screen.

- explore relation between physical quantities

  e.g. *find out how the [extension - increase of length] of a spring depends on the [load - mass] attached to it;*

  find out how temperature and concentration of reagents affect the rate of an enzyme reaction.

- explore relation between objects and physical quantities

  e.g. *compare rates of reaction of a selection of metals with dilute acid;*

  investigate the effect of caffeine on rate of heartbeat.

Another type of labwork task is one which is designed to help students to develop their ideas by seeing that a new concept, or quantity, can help them to interpret their observations. Here the student is intended to:

- 'invent' (or 'discover') a new concept (physical quantity, or entity)

  e.g. *identify the need for (or the usefulness of) the quantity defined as energy/time (power) in accounting for a set of observations;*

  identify that, for a weak acid, the ratio: log ($[H^+].[A^-]/[HA]$) is constant and can be used to characterise the strength of the acid.

Some labwork tasks focus on measuring a physical quantity, using an indirect method. Here students are applying their ideas to obtain a numerical value of the quantity:

- determine the value of a quantity which is not measured directly

  e.g. *measure the acceleration due to gravity using the relationship* $T = 2\pi\sqrt{\frac{l}{g}}$ *for a simple pendulum;*

  measure the thermal conductivity of a material;

  determine the number of molecules of water of crystallisation associated with each molecule of a salt using volumetric analysis.

Another type of labwork task involves the testing of predications. A prediction may be simply a guess, or it may be deduced from a more formal understanding of the situation, such as an empirical law, or a theory (or model). In labwork tasks of these sorts students are intended to:

- test a prediction based on a guess

  e.g. *test the prediction that rubber-soled shoes provide better 'grip' on a wooden floor;*

  guess that a sample of soil is mainly limestone and test for effervescence when dilute acid is added.

- test a prediction from a law

  e.g. *test whether the increase in length (extension) of a piece of elastic is directly proportional to the load applied, up to a limit (as predicted by Hooke's Law);*

  test whether the electric current through a given conductor is proportional to the applied p.d. (as predicted by Ohm's Law).

- test a prediction from a theory (or a model based on a theoretical framework)
  e.g. *a model of the mechanism of a chemical reaction predicts a certain relationship between rate of reaction and temperature; test this by comparing it with what is actually observed;*
  predict the pH of a solution of ethanoic acid of given concentration using the formula: pH = $\frac{1}{2}(pK_a - \log [c])$ *and then check this by measurement;*
  theory of fluid flow predicts that the volume of fluid per second (Q) flowing through a pipe is related to pressure difference (P), radius (r) and length (l) by the equation: $Q = \frac{P\pi r^4}{8\eta l}$*, where* η *is the viscosity of the liquid. Carry out a series of measurements to test this relationship in the case of water.*

Finally, some labwork tasks are about <u>accounting for observations</u>, either by relating them to a given explanation or by proposing an explanation. An 'explanation' might be an empirical law, or a general theory, or a model derived from a general theory, or general principles derived from a theoretical framework. In some tasks, the explanatory ideas are known in advance and the student is expected to use these to account for what is observed, perhaps extending or modifying the framework of ideas. A variant of this is where two (or more) possible explanations are proposed and the task is to decide which accounts better (or best) for the data. In other tasks, the observations come first, and the student is expected to select
an explanation from his/her existing knowledge, or perhaps to extend this to develop an explanation.

- account for observations in terms of a given explanation
  e.g. *explain similarities and differences between related species of birds in terms of a given account of their evolution;*
  explain the observed motion of a water rocket using Newtonian dynamics.

- account for observations by choosing between two (or more) given explanations
  e.g. *is the behaviour observed when the temperature of a sample of air is raised better explained by saying that 'hot air rises' or 'air expands when heated'.*

- account for observations by proposing an explanation
  e.g. *from observation of the objects and variables in an environment, propose a model to explain some aspect of the interactions within that environment;*
  measure the temperature of a sample of water in a calorimeter over a period of minutes as it is heated by an immersion heater. Explain the shape of the temperature-time graph produced.

All of these categories are summarised in Table 2 below. Rather than simply ticking one or more lines to characterise the task, the position of the tick in columns 3-5 can also be used to indicate the nature of the tools available for processing the information obtained.

What students are intended to do with ideas		Tools to be used for processing information (tick as appropriate)		
		manual	pocket calculator	computer
report observation(s)				
identify a pattern				
	objects			
explore relation between	physical quantities (variables)			
	objects and physical quantities			
invent' (or 'discover') a new concept (physical quantity, or entity)				
determine the value of a quantity which is not measured directly				
	from a guess			
test a prediction	from a law			
	from a theory (or a model based on a theoretical framework)			
	in terms of a given explanation			
account for observations	by choosing between two (or more) given explanations			
	by proposing an explanation			

Table 2 A classification of labwork tasks according to what students are intended to do with ideas

4.2.3 Observation- or ideas-driven?

The third aspect of the design of a labwork task concerns the relationship between the two domains: of objects and observables, and of ideas. Some tasks are presented in an 'object-driven' way: the student is required to carry out some operations on objects from which, it is hoped, ideas will emerge. Other tasks are presented in an 'ideas-driven' way: the operations on objects being specifically undertaken to explore some ideas which have been stated in advance. Of course, to some extent, all observation is guided by the ideas of the observer (or the teacher giving the instructions). This dimension of the 'map' is intended to reflect the emphasis in the labwork task. The task can be characterised as:

a What the students are intended to do with ideas arises from what they are intended to do with objects;

b What the students are intended to do with objects arises from what they are intended to do with ideas;

c There is no clear relationship between what the students are intended to do with objects and with ideas.

4.2.4 *Degree of openness/closure*

This dimension of the design of the labwork task describes the extent to which the student is able (or required) to specify aspects of the task. The pattern of ticks in Table 3 provides an indication of the degree of openness or closure of the task.

Aspect of labwork task	**Specified by teacher**	**Decided through teacher-student discussion**	**Chosen by students**
	(tick as appropriate)		
Question to be addressed			
Equipment to be used			
Procedure to be followed			
Methods of handling data collected			
Interpretation of results			

Table 3 Degree of openness/closure of a labwork task

4.2.5 *Nature of student involvement*

The fifth and final dimension of the task design concerns the nature of student involvement in the labwork task. A labwork task can be classified as belonging to one of the categories below:

a demonstrated by teacher; students observe
b demonstrated by teacher; students observe and assist as directed (e.g. in making observations or measurements)
c carried out by students in small groups
d carried out by individual students

4.3 Dimension B.2: Context of the task

The second dimension of aspect B in Figure 3 is the context of the labwork task. Four sub-dimensions can be identified:

1. how much time is given to the task
2. which people the student is expected to interact with in carrying out the task
3. what information sources are available to the student to assist with the task
4. what type of apparatus is involved in carrying out the task.

4.3.1 *Duration*

Perhaps the commonest duration for a labwork task is a single science lesson of around 60-80 minutes. Some tasks, however, such as a demonstration, may require a shorter time, whilst work on an extended project may stretch over several weeks. The four categories used are chosen to accommodate and reflect this variation in time allocation.

a very short (less than 20 minutes)
b short (one science lesson, say, up to 80 minutes)
c medium (2-3 science lessons)
d long (2 weeks or more)

4.3.2 People with whom student interacts

In carrying out a labwork task, a student may interact with other people, such as fellow students, other (perhaps more advanced) students, the teacher, technicians, and so on. This can be indicated by selecting one or more from the following list:

a other students carrying out the same labwork task
b other students who have already completed the labwork task
c teacher
d more advanced students (demonstrators, etc.)
e others (technician, glassblower, etc.)

4.3.3 Information sources available to student

Students may carry out a labwork task by following a set of written instructions, from a worksheet, or a textbook. Other information may be available, such as data books, or computer databases of information. The range of information sources used can be indicated by selecting one or more from the following list:

a guiding worksheet
b textbook(s)
c handbook (on apparatus), data book, etc.
d computerised database
e other

4.3.4 Type of apparatus involved

Finally, although most labwork tasks will make use of standard laboratory equipment, some will also involve the use of an interface to a computer. Also, in science courses emphasising the links between science ideas and everyday life, the apparatus involved may be everyday equipment rather than specialised science laboratory equipment. The type of equipment used can be indicated by selecting one or more from the following list:

a standard laboratory equipment

b standard laboratory equipment + interface to computer
c everyday equipment (e.g. kitchen scales, domestic materials/equipment, etc.)

Acknowledgements

The labwork 'map' described above has been developed as a tool for use within the EU-funded project Labwork in Science Education (LSE). Its development has been enriched at various stages by fruitful discussions with many colleagues involved in the LSE project.

Appendix 1: A proforma for summarising the characteristics of labwork tasks

A Intended learning outcome (learning objective)

To help students:

a	identify objects and phenomena and become familiar with them	
b	learn a fact (or facts)	
c	learn a concept	
d	learn a relationship	
e	learn a theory/model	

f	learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus	
g	learn how to carry out a standard procedure	
h	learn how to plan an investigation to address a specific question or problem	
i	learn how to process data	
j	learn how to use data to support a conclusion	
k	learn how to communicate the results of their work	

B.1 Design features of task

1 What students are intended to do with objects and observables

[Origin of information acquired by students:

IL, OL **-** from real world: inside, outside laboratory;

V **-** from video ; C **-** from CD-ROM or computer ; T **-** from text

Type of data:

Qt, SQt, Ql for quantitative, semi**-**quantitative or qualitative**]**

use	an observation or measuring instrument	
	a laboratory device or arrangement	
	a laboratory procedure	
present/display	an object	
make	an object	
	a material	
	an event occur	
observe	an object	
	a material	
	an event	
	a quantity	

2 What students are intended to do with ideas

[Tools available for processing information:

M **-** manual ; PC **-** pocket calculator ; C **-** computer**]**

report observation(s)		
identify a pattern		
explore relation between	objects	
	physical quantities	
	objects and physical quantities	
'invent' a new concept (physical quantity, or entity)		

determine the value of a quantity which is not measured directly		
test a prediction	from a guess	
	from a law	
	from a theory (or model based on th. f'work)	
account for observations	in terms of a given explanation	
	by choosing between explanations	
	by proposing an explanation	

3 Observation- or ideas-driven?

a What the students are intended to do with ideas arises from what they are intended to do with objects;	
b What the students are intended to do with objects arises from what they are intended to do with ideas	
c There is no clear relationship between what the students are intended to do with objects and with ideas	

4 Degree of openness/closure

T Specified by teacher
TS Decided through teacher-student discussion
S Chosen by students

Question to be addressed	
Equipment to be used	
Procedure to be followed	
Methods of handling data collected	
Interpretation of results	

5 Level of student involvement

a demonstrated by teacher; students observe	
b demonstrated by teacher; students observe and assist as directed (e.g. in making observations or measurements)	
c carried out by students in small groups	
d carried out by individual students	

B.2 Details of context

1 Duration

a very short (less than 20 minutes)	
b short (one science lesson, say, up to 80 minutes)	
c medium (2-3 science lessons)	
d long (2 weeks or more)	

2 People with whom student interacts

a other students carrying out the same labwork task	
b other students who have already completed the task	
c teacher	
d more advanced students (demonstrators, etc.)	

e others (technician, glassblower, etc.)	

3 Information sources available to student

a guiding worksheet	
b textbook(s)	
c handbook (on apparatus), data book, etc.	
d computerised database	
e other	

4 Type of apparatus involved

a standard laboratory equipment	
b standard laboratory equipment + interface to computer	
c everyday equipment (kitchen scales, domestic materials...)	

From the common work of the project
'LABWORK IN SCIENCE EDUCATION',
some policy implications :
A summary

The following research themes have been addressed at European level by the project :
- the current practice of labwork in Europe [Working papers 2, 3] using a specific tool of description of labwork sessions [Working Paper 1]
- the identification of labwork objectives as defined and ranked by teachers in order of importance [Working Paper 6]
- the image of science as it is related to labwork [Working Papers 4 and 5]
- the effectiveness of labwork which has been documented by 22 case-studies [Working Papers 7 and 8]

These pieces of work showed that there is in Europe a common paradigm of labwork, but that some choices for Education and Science Education are stemming from national traditions. However some implications could be drawn from the work done in six countries, which are summarised below.

1 - Some objectives are not achieved if not addressed specifically. A number of potential objectives are very rarely addressed currently. If these issues were addressed, there is a potential for students to learn more from labwork.

The objectives being defined carefully, it is necessary to attribute a specific place and role to each of them.

❖Although ***conceptual knowledge*** underpins all labwork activities, this should not be taken as implying that doing labwork activities necessarily leads to improved conceptual understanding. Indeed, scientific concepts are not usually learned effectively through labwork if the labwork activity is not designed towards this aim.

Some case studies show the proportion of time devoted to "talk" about the conceptual and theoretical basis of labwork tasks. In general, the amount of time spent by students in this way is very small, suggesting a need for improvement.
One of the most effective ways of focusing students on the corresponding knowledge, is to address issues of modelling directly. This is made possible in activities such as constructing a model, discussing a model in relation to events, using a model in particular situations, comparing models and searching for the value of a parameter to fit a model. Computers are of great help in such cases, as can videos designed to focus on the theoretical underpinnings of labwork.
The context of open-ended project work is also a powerful strategy because it requires students to draw upon conceptual knowledge in order to solve a given problem, even if the project is introduced before formal teaching of ‘theory’.
Another possibility is to ask students to make predictions more often about the behaviour of events, or alternatively about orders of magnitude before actually making measurements. To be meaningful, this requires renewed types of organisation.

❖ Any piece of labwork requires students to undertake ***procedures***. However teachers cannot expect students to learn about procedures effectively if these are not taught explicitly, and explained and used in a variety of contexts. An argument supporting the teaching of procedures is that, once understood, such procedures are powerful tools to be used in designing experiments, one of the most creative processes in science. Experimental design is a particularly effective context for teaching epistemological knowledge. If students are not taught procedures, then their autonomy for designing experiments will inevitably be reduced.

❖ During labwork there should be a constant interplay between the ***collection of data*** (observations, measurements etc.) and theory. During the project, the place of measurement was increasingly questioned. If measurement is undertaken as an activity, it should be carefully ‘targeted’: clear objectives for the activity should be set, and consideration should be given to other activities that might follow on from measurement such as data processing, the evaluation of theories, drawing conclusions and evaluating experimental techniques and apparatus.
Obviously, computers and sensors can play an important role in saving time during these tasks and in some cases it is only possible to make measurements with the aid of computers. But, the significance of the measurement must be addressed directly in teaching and not hidden behind routines.

❖ ***Data processing and the development of conclusions*** provide opportunities for the development of conceptual and epistemological understanding by students. Our work underlines the very different choices that can be made by teachers. Data processing can be treated as an algorithm, or alternatively can be treated as an opportunity to teach about one of the most important aspects of epistemology: the confidence that can be attributed to data and the uses to which data can be put.

❖ The development of ***epistemological knowledge*** is rarely addressed in most countries, and in countries where it is addressed, labwork is not the teaching method used. There are opportunities in labwork to promote a reflection on the part of students upon links between theory and data. One approach involves addressing experimental design. Another approach involves the selection of real situations from ongoing research, addressing how the research was operationalised and the main issues addressed during the work as it proceeded.

This raises the issue of the extent to which an unique epistemology can and should be presented to students through labwork, and indeed through the science curriculum more generally. It is necessary to address at a policy level the relative placing of examples from the history of science in the curriculum, and the treatment of epistemology in students' labwork.

2 - Each labwork session should be reasonably ambitious and targeted, the strategy being a clear orientation towards certain objectives.

In fact there is frequently a mismatch between teachers' objectives and what is achieved by students. Students *'do'* what they are intended to do but they do not necessarily *'think'* or *'learn'* as they are intended to think and learn. Teaching strategies ought therefore to be adapted to address selected objectives, putting other possible objectives aside. This is what we call '*targeted*' labwork sessions.

With this choice, it becomes necessary to organise students' overall programme of labwork activities within a coherent long-term programme and this assumes that the types of labwork undertaken by students should be varied. For example, selected part of the whole experimental process, studies of identified cases encountered in labs to teach images of science, qualitative observations, software used simultaneously with an experiment, computer simulations and projects might all be included within a sequence. Projects are particularly useful in ensuring that students work under their own direction. If this is to happen a generous time allocation has to be given to project work, possibly several weeks. This supposes to accept to diminish a curriculum crowded by content.

3 - A major outcome of the project is recognising the importance of differentiating between the effectiveness of labwork in terms of promoting learning outcomes, and in terms of the success of labwork at engaging students in particular activities. Both types of effectiveness should be involved in labwork.

It is particularly important for students to be given the opportunity to undertake experimental approaches for themselves, to design experiments, to go through a complete sequence of data processing and to make corresponding decisions about the choice of apparatus, mathematical tools or software. Such activities during labwork cannot be directly linked to specific learning outcomes. However they are crucial for the development of students' scientific understanding in the broader sense.

Linked to effectiveness, specific assessment strategies have to be implemented. Some suggestions about the wording of questions allowing the assessment of specific objectives such as procedures or epistemological meta-knowledge, can be found in case studies from the project.

4 - A condition for improved effectiveness is a different focus for teacher education and a deep change in the focus of resources, labwork sheets and the types of guidance available to students during labwork.

The critical role of teachers in ensuring that labwork is effective was emphasised.

For instance, some teachers have a role of labwork developers: they should work in collaboration to identify learning objectives, possibly consulting literature and/or the Internet. They should also abandon some possible learning objectives to promote others identified as being particularly important. They have to design lectures to be done at a level and with objectives consistent with labwork. In addition, during labwork, teachers have to ask questions to students, and require them to make observations or measurements, calculations of orders of magnitude, mathematical modelling, predictions, etc. as described previously.
The multiple tasks of teachers suggest that it requires specific input during initial and in service training.

The general objectives of promoting student ***autonomy and motivation*** have not been addressed directly in this project. However there is agreement that student autonomy is not only obtained during open ended labwork, but rather that it can be obtained during labwork organised in various different ways in which specific questions are raised in students' minds, and particular guidance is given to students.

Autonomy and motivation are expected as consequences of targeted labwork.

Working Papers
of the project
'LABWORK IN SCIENCE EDUCATION'

1998

*** Working paper 1 ***

A MAP OF THE VARIETY OF LABWORK IN EUROPE

Authors : Robin Millar, Jean-François Le Maréchal and Christian Buty

Language : English .

Annex : The 'map' in one of the national languages

*** Working papers 2 and 3 ***

SCIENCE TEACHING AND LABWORK PRACTICE IN SEVERAL EUROPEAN COUNTRIES

Volume 1 Description of science teaching at secondary level
Authors : Andrée Tiberghien, Karine Bécu-Robinault, Christian Buty, Manuel Fernandez, Hans Fischer, John Leach, Jean-François Le Maréchal, Anastasios Molohides, Albert Chr.Paulsen, Didier Pol, Dimitris Psillos, Naoum Salame, Carlo Tarsitani, Eugenio Torracca, Laurent Veillard, Stefan v. Aufschnaiter and Jean Winther

Volume 2 Teachers' labwork practice, an analysis based on questionnaire at secondary and university levels

Authors : Andrée Tiberghien, Karine Bécu-Robinault, Christian Buty, Hans Fischer, Kerstin Haller, Dorte Hammelev, Lorenz Hucke, Petros Kariotoglou, Helge Kudahl, John Leach, Jean-François Le Maréchal, Jenny Lewis, Hans Niedderer, Albert Chr.Paulsen, Dimitris Psillos, Florian Sander, Horst Schecker, Marie-Genevieve Séré, Carlo Tarsitani, Eugenio Torracca, Laurent Veillard, Stefan v. Aufschnaiter, Manuela Welzel and Jean Winther

Volume 3 Analysis of labwork sheets used in regular labwork at the upper secondary school and the first years of University

Authors : Andrée Tiberghien, Laurent Veillard, Jean-François Le Maréchal and Christian Buty

Annexes: Examples of labsheets translated into English form several European countries

Language **:** English

*** Working paper 4 ***

SURVEY 2 : STUDENTS' 'IMAGES OF SCIENCE' AS THEY RELATE TO LABWORK LEARNING.

Authors : John Leach, Robin Millar, Jim Ryder, Marie-Geneviève Séré, Dorte Hammelev, Hans Niedderer and Vasilis Tselfes,.

Language : English

*** Working paper 5 ***

TEACHERS' IMAGE OF SCIENCE AND LABWORK. HYPOTHESES, RESEARCH TOOLS AND RESULTS IN ITALY AND IN FRANCE

Authors : Milena Bandiera, Francesco Dupré, Marie-Geneviève Séré, Carlo Tarsitani, Eugenio Torracca and Matilde Vicentini.

Language : English

*** Working paper 6 ***

TEACHERS' OBJECTIVES FOR LABWORK. RESEARCH TOOL AND CROSS COUNTRY RESULTS

Authors : Manuela Welzel, Kerstin Haller, Milena Bandiera, Dorte Hammelev, Panagiotis Koumaras, Hans Niedderer, Albert Paulsen, Karine Bécu- Robinault and Stephan von Aufschnaiter

Language : English

*** Working paper 7 ***

CASE STUDIES OF LABWORK IN FIVE EUROPEAN COUNTRIES

Editors : Dimitris Psillos and Hans Niedderer

Language : English

*** Working paper 8 ***

THE MAIN RESULTS OF CASE STUDIES : ABOUT THE EFFECTIVENESS OF DIFFERENT TYPES OF LABWORK

Authors : Dimitris Psillos, Hans Niedderer and Marie-Geneviève Séré

Language : English

*** Working paper 9 ***

CATEGORY BASED ANALYSIS OF VIDEOTAPES FROM LABWORK : THE METHOD AND RESULTS FROM FOUR CASE-STUDIES

Authors : Hans Niedderer, Andrée Tiberghien, Christian Buty, Kerstin Haller, Lorenz Hucke, Florian Sander, Hans Fischer, Horst Schecker, Stefan von Aufschnaiter and Manuela Welzel.

Language : English

*** Working paper 10 ***

LES TRAVAUX PRATIQUES DANS L'ENSEIGNEMENT DES SCIENCES DE LA VIE ET DE LA TERRE DANS LES LYCÉES FRANÇAIS

Editors : Didier Pol , Naoum Salamé et Marie-Geneviève Séré

Language : French.

The part concerning the survey *Science Teaching and Labwork Practice in Several European countries*, in English

*** Working papers in each country (France, Denmark, Germany, Great Britain, Greece, Italy) ***

THE MAIN RESULTS OF THE SURVEYS OF THE EUROPEAN PROJECT *'LABWORK IN SCIENCE EDUCATION'*

Language : the national language in each country .

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Scientific papers, communications, proceedings and theses concerning the project, can be found in the ANNEX 11 to the final report of the project.
All these publications are available at the following address: Marie-Genevieve.Sere@didasco.u-psud.fr,
or at the electronic address of one of the authors, to be found via the CORDIS site of the European Commission.
http ://www.cordis.lu/