“Improving Science Education : issues and research on innovative empirical and computer-based approaches to labwork in Europe”

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“Labwork in Science Education”

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“Improving Science Education : issues and research on innovative empirical and computer-based approaches to labwork in Europe”

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Content

Background and objectives of the project
'Labwork in Science Education '

In June 1995, the research proposal *'Labwork in science Education'* was written to address the work content of the Fourth call of *Targeted Socio-economic Research*. Given their expertise and competencies, the future group-leaders were keen to address the general concern of DGXII with education, and specifically Science teaching. It was decided to provide :

- a new formulation of objectives to meet new needs
- study and elicitation of the general advantages of specific aspects of national systems of Education
- an overview of the key competencies promoted through labwork with respect to the labour market
- awareness of the evolution of the educational systems

A general aim was also to constitute a community of researchers able to take forward collaboration at European level.

Towards these various aims, a topic specific of natural sciences was chosen, namely the place of experiments in teaching, generally called labwork. Though often studied in the community of international researchers, a strong basis of mutual knowledge in the European context was missing on this subject.

Financially speaking, this form of teaching is rather expensive. Several countries in Europe spend highly on it, suggesting the relevance of addressing the effectiveness of labwork. Socially speaking, laboratory teaching has a high potential. In addition, the variety of knowledge that it makes possible to be acquired is wide open, as it was intended to demonstrate in the project. The most adapted academic levels for such a theme of research was judged to be Upper secondary school and Undergraduate level at University. Though concerning a rather limited and variable part of the population of young people according to the country, these levels of study are critical for scientifically educated people, be they destined to work as professional scientists in the future, or otherwise.

During the course of the project, a movement of reform of Education developed at University level as well as at Secondary level, spread out in several countries. Some members of the consortium were involved in such reforms and could point at key aspects of the common work to be taken into account in national decisions. Mainly because of these current reforms, prolongation was required for three months more and accepted by DGXII.

At the time of writing the final report, this movement of reform is now clearly identified as aiming at an European dimension, mainly at University level. So the project members' expectation is to provide knowledge of the current practice and results concerning effectiveness for Science Education, directly useful for the academic community. It is also to continue to work in the same European direction.

EXECUTIVE SUMMARY:

'LABWORK IN SCIENCE EDUCATION'

This project focused upon the use of labwork in teaching physics, chemistry and biology to students in academic science streams in the years of upper secondary schooling and the first two years of undergraduate study. Work was conducted in 7 European countries. 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 number of pieces of work were therefore conducted:

- A conceptualisation of the variety of labwork, including possible learning objectives, modes of organisation, and the notion of effectiveness of labwork in promoting learning. This is referred to as the *'Map of the variety of labwork'*.

- A survey of current practice in the use of labwork. This is referred to as the survey of *'Current labwork practices'*.

- A survey of the images of science that students draw upon during labwork. This is referred to as the survey of *'Students' images of science'*.

- A survey of the images of science that teachers draw upon during teaching and especially labwork. This is referred to as the survey of *'Teachers' images of science'*.

- A survey of the learning objectives attributed to labwork by teachers, referred to as the survey of *'Teachers' objectives for labwork'*.

- A set of 23 case studies of labwork practice, together with an analysis of the effectiveness of labwork in promoting learning.

Management and realisation of the work

The Consortium involved 7 research groups from 6 European countries

		GROUP-LEADERS
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Great Britain	The University of Leeds; LIS Group; The University of York, Science Education Group	Dr. J. Leach
Germany	University of Bremen; Institut für Didaktik der Physik; University of Dortmund	Prof. Dr. H. Niedderer
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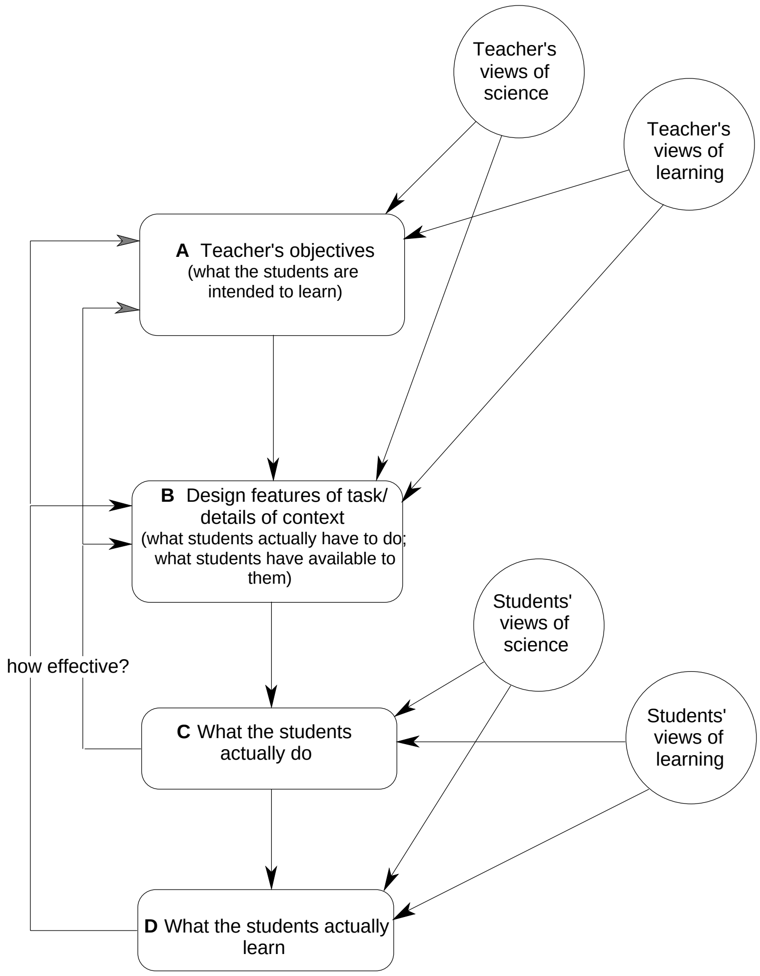
Prof. M-G. Séré (DidaScO group) was responsible for the overall co-ordination of the work. The survey of current labwork practices was managed by the COAST group. The survey of students' images of science and the production of the map of the variety of labwork were co-ordinated by the British group. The survey of teachers' images of science was conducted by the Italian group. The survey of teachers' objectives for labwork was co-ordinated by the German group. All groups except the Danish group conducted case studies; these were co-ordinated by the Greek and German groups.

1 - Findings in summary

1 . 1 A research tool of description and conceptualisation:
'Map of the variety of labwork'
The boundary between labwork and other science teaching/learning activities is not clear-cut and is, indeed, somewhat arbitrary. However despite the absence of a clear-cut line of demarcation, '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.

In order to define more precisely what is meant by labwork, how it is designed, what is done by students and what is learnt by them, a map was produced to model the design and evaluation of a labwork task and the influences on each:



The design of a teaching/learning task might be thought to start with the learning objectives the teacher has in mind (Box A): 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). In designing the teaching/learning task, the teacher intends that the students will do something when given the task. So the model 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.

Influences upon students actions and learning during labwork include their images of science and their images of learning. Similarly, influences upon the ways in which teachers design labwork include their images of science and their images of learning. For this reason, surveys were conducted to investigate students' and teachers' images of science, and teachers' views about appropriate learning objectives for labwork.

The model set out above is 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).

Subsets of categories in boxes A, B, C and D were generated, and used valuably as a tool for describing work in various aspects of the project. In particular, the map was successfully used to analyse labwork sheets in biology, chemistry and physics in different European countries as described in the next section.

1 . 2 Survey: *'Current labwork practices'*

Participating countries: Denmark, France, Germany, England, Greece, Italy and Spain.

The aim of this survey was to present an overview of labwork practice in the participating countries. To this end, the study addressed three issues:

- the organisation of science teaching at the upper secondary and university levels. Data source: existing documentary information in each participating country.
- teachers' practices in terms of labwork at an organisational level (time spent etc.). Data source: survey of teachers' responses (n=397).
- more specific aspects of teachers' practice (such as the sorts of activities used). Data source: analysis of labwork sheets (n=180) using the *'Map of the variety of labwork'*.

Considerable diversity in the organisation of science teaching for students in academic science streams at the upper secondary and university levels was noted. In some countries (notably France) a whole curriculum orientation is selected by students for study at upper secondary school (e.g. sciences, arts) whereas in other countries (notably Great Britain) students have considerable autonomy in selecting individual subjects. Another key variable between countries is the extent to which the upper secondary science curriculum is subject to central control. In some countries (e.g. Denmark, Greece and France) time allocations and assessment structures for each subject are specified centrally, whereas in others (e.g. Germany, Great Britain, Italy and Spain) control is more local. In terms of the amount of labwork practised, there were three main groups of countries. In Denmark, Great Britain and France labwork is regularly performed by upper secondary students, in

Germany the situation is dependent upon the wishes of individual teachers, and in Italy and Greece labwork is rarely performed by upper secondary students in academic streams. However, the use of demonstrations by teachers is common in all countries.

At the university level, labwork is commonly used in all countries and for all disciplines. At both secondary school level (if labwork is done) and university level, the type of labwork used vary little between countries or disciplines. By far the most common pattern of organisation is for small groups of students to work with real objects/materials following very precise instructions about methods and analysis given by a teacher or a written source (referred to as a 'labwork sheet'). The use of open-ended project work is rare, particularly during the first two years of undergraduate study. Labwork is mainly assessed by grading reports from labwork according to the quality of students' descriptions of the way in which tasks were performed, data acquisition, discussion of the quality of data and interpretation of experimental results.

There is some difference in the extent to which labwork is linked to lecture courses. At upper secondary school level, labwork and lectures are typically more closely linked than at university level. At the university level there were very minor national variations in links between labwork and lectures, links being closer in Italy, Greece and Denmark than in Great Britain, France and Germany.

Labwork sheets from several European countries were selected by the participating research groups as typical of the labwork normally carried out (n=175). The results of their analysis using *'The map of the variety of labwork'* are striking not only from the point of view of what the students have to do but also from what they do not have to do. At upper secondary school, the students normally have to use standard procedures, to measure, and to report observations directly. They do not have to present or display or make objects. They do not have to explore relationships between objects, to test predictions, to select between two or more explanations and so on. Even at university, it is rare for students to have to test a prediction made from a guess or a theory or to account for observations in terms of a law or theory, although sometimes in physics students are asked to test a prediction made from a law). In effect, the similarities both between disciplines and countries in terms of typical labwork is more than might be expected, given the differences in educational systems in each country. Typical labwork apparently involves a few similar types of activities.

1 . 3 Survey: *'Students' images of science'*

Participating countries: Denmark, France, Germany, Great Britain, Greece.

This study was designed to provide information about the images of science drawn upon by science students during labwork. By 'images of science' we mean the profile of ideas about the epistemology and sociology of science used by individuals in specific contexts for specific purposes. In the case of labwork, students draw upon images of science to explain the purposes of empirical investigation, relationships between data and knowledge claims, and relationships between knowledge claims and experimental design, analysis and interpretation of data. As individuals are viewed as having a number of images of science that might be deployed in a given situation, no attempt was made to classify individual students as thinking in a particular way. Rather, findings from the study have been used to identify ways of thinking used by large numbers of students in a variety of situations.

Labwork might well develop students' conceptual understanding, or their skills in planning investigations, or their aptitudes at using standard laboratory procedures in carrying out investigations. Many students in teaching laboratories often work with knowledge claims already agreed as reliable within the scientific community. For example, they may be involved in work to illustrate accepted theories or to apply accepted theory in specific contexts. Their ideas about how that knowledge came to be viewed as reliable may well influence their labwork. For all these reasons, participation in labwork involves students in drawing upon epistemological understanding.

In order to investigate the epistemological understanding that students might draw upon during labwork, responses were collected to 5 written survey questions from 661 students in the participating countries. These questions focused upon students' views on the nature of the data collected during labwork, links between data and knowledge claims in labwork, and the ways in which decisions are made about data collection and drawing conclusions during labwork.

Three 'images of science' appeared to by used by significant numbers of students in a variety of contexts. These were:

- A 'data-focused view', in which students appeared to view the process of data collection as a simple one of description of 'the real world'. For example, 12% of the university students in the sample stated that the best estimate of a value from a set of measured data should correspond to a measured value, and 28% of university students suggested that the process of proposing a relationship between two variables was a simple matter of following a routine algorithm to join measured points.
- A 'radical relativist view', in which students appeared to view the process of drawing conclusions as so problematic that it is never possible to select one explanation as being better than another one. For example, 16% of university students suggested that it is up to individual scientists to decide how to interpret a given data set as there is no way of determining between two contrasting views.
- a 'theory and data linked view', in which theory, data and methodological aspects of labwork are viewed as inter-related, each in principle being able to influence the other.

From this, it appears that many students are likely not to recognise the epistemological basis of routine algorithmic procedures used for data handling during labwork, such as estimating values from sets of data and drawing lines and curves through measured data points. In some cases, this is likely to lead to students taking inappropriate actions during their labwork learning (such as assuming that computers can solve problems of data analysis, not recognising the need for scientists to instruct computers how to handle data according to specific requirements determined by theoretical considerations). Findings from this study suggest that individual students draw from a range of images of science in acting in various situations. For many students, it may therefore be necessary to introduce ideas about the epistemological basis of routine algorithms for data analysis, as well as to give students experience and practice at applying this reasoning in a variety of appropriate labwork contexts.

It also appears that many students are likely to see knowledge claims as emerging directly from the logical analysis of data, not recognising how particular theories and models help to shape scientists' ways of evaluating and interpreting data. This may lead to inappropriate behaviour during labwork, such as students not recognising how theory might be drawn upon during experimental design, analysis and interpretation, or students appearing likely to draw strong conclusions from investigations carried out in labwork, based on inconclusive evidence.

1 . 4 Survey: *'Teachers' images of science'*

Participating countries: Italy, France.

This study was conducted on the assumption that the development of a reasonable image of science must be an objective of science teaching. This argument is put forward for cultural reasons, and for democratic reasons. To understand science should be integral part of a "modern" education for the average citizen, particularly as part of a contemporary European democracy in which citizens should be able to understand scientific results as presented in the mass media, and even participate with some competence in political decisions with scientific aspects.

Teachers have a special place in communicating an image of science to their students. It is therefore important to know something of the images of science drawn upon by teachers. To this end, responses to 10 survey questions were collected and analysed from a sample of 145 teachers from Italy and France.

From the responses to these questions, a questionnaire for research could be elaborated and some tentative conclusions be drawn about the common core of images of science of the teachers in the sample:

- Scientific research is founded on a method which requires sound observations and controllable experiments.
- In the interpretation of experiments, scientists are guided by theoretical assumptions.
- Empirical investigation is needed to confirm the scientific validity of any statement.
- Conflicting interpretation of data may be due to an inadequate experiment design, to theoretical commitments (most of the University teachers) or to problems of data analysis (most of school teachers).

For the given sample, differences between the ideas proposed by teachers at the school and university levels, were generally not very strong. Further research would be of great interest in this direction.

1 . 5 Survey: *'Teachers' objectives for labwork'*

Participating countries: Denmark, France, Germany, Great Britain, Greece, Italy.

This survey was designed to investigate the learning objectives identified by teachers as important for labwork, with particular reference upon any differences in objectives between disciplines, countries or levels.

In order to identify the learning objectives actually considered important by teachers, a three stage methodology was used. In the first instance, a sample of teachers (n=60) were asked open-ended questions about the learning objectives that they saw as important for labwork. Second, data categories of objectives were abstracted from these responses and compared with categories reported in the literature. Third, these categories were formulated as a number of closed-response statements to be ranked and rated by a larger sample of teachers. Findings from the survey address the main objectives identified by teachers as important for labwork, and the relative effectiveness of different types of labwork at reaching those objectives.

Teachers were presented with five overall objectives for labwork. These were:

- To link theory to practice
- Learning experimental skills
- Getting to know the methods of scientific thinking
- Fostering motivation, personal development and social competency
- Evaluating the knowledge of students

These had to be ranked in order from most important to least important by the teachers. More than 40% of the teachers surveyed identified the main objective of labwork as being ‘to link theory to practice’. This objective was rated higher by physics teachers than by teachers of biology and chemistry. The objectives of ‘learning experimental skills’ and ‘getting to know the methods of scientific thinking’ were also rated highly. The objective ‘learning experimental skills’ was rated more highly by university teachers than by upper secondary teachers. The objective ‘getting to know the methods of scientific thinking’ was rated more highly by biology teachers than by teachers of chemistry and physics. ‘Fostering motivation, personal development and social competency’ and ‘evaluating the knowledge of students’ were rated low. Differences between country samples show only minor differences, e.g. in the French sample ‘to develop scientific thinking’ shows the highest average rank value.

Five organisational patterns for labwork were presented to teachers. These were:

- experiments carried out by the students
- open ended labwork
- using modern technologies
- strongly guided experiments
- demonstration experiments

Teachers were asked to rank each type of labwork according to how useful it was at promoting the learning objectives listed above. It was apparent that ‘experiments carried out by the students’ were seen as overwhelmingly useful for promoting all learning objectives of labwork. Open-ended labwork was also viewed as useful, though less so for the learning objectives of ‘linking theory and practice’ and ‘learning experimental skills’. Experiments using modern technologies and strongly guided labwork were all seen as useful for promoting all learning objectives, though both types were not seen as particularly effective at motivating students or evaluating students' knowledge. Demonstration experiments were viewed as being not particularly effective at motivating students and evaluating their understanding, but more useful for 'linking theory and practice'.

Overall, the results from this survey are important as a frame for possible objectives of labwork, focusing on those objectives which are ranked as particularly important by teachers. Possible future work involves comparing findings from this study about the objectives that teachers see as important for labwork, with findings from case study work about the effectiveness of labwork at promoting students' learning.

1 . 6 Case studies of the practice of labwork and analysis of effectiveness

The case study method was adopted as a multifaceted research methodology potentially capable of examining the influence of particular organisational and personal factors on labwork and of identifying, describing and documenting students' actions and cognitive processes that take place during labwork. 23 case studies were carried out in six participating groups, allowing for an in-depth investigation in a variety of contexts of how students' understandings of several aspects of scientific knowledge and inquiry may be facilitated by different types of labwork. Although there are more case studies at university level than at secondary education, and more in Physics than in other scientific disciplines the variety of case studies allowed for new research questions and has revealed several objectives which may be pursued by labwork.

The case studies were diverse in focus. For example, some case studies focus on the evolution and acquisition of conceptual knowledge by students following labwork; some case studies investigate implicit objectives set out by instructors while other case studies have stated clearly their objectives; the relation between aspects of what the students do and what they learn from laboratory activities is investigated in some other case studies; the effectiveness of carrying out new teaching strategies is the foci of other case studies. A number of case studies were characterised by explicit discussion of the epistemologies and theories of learning that underpinned their methodology.

A characteristic of the case studies was that they did not focus only on learning outcomes following labwork, but a number of them addressed students' intellectual or manipulative activities during labwork.

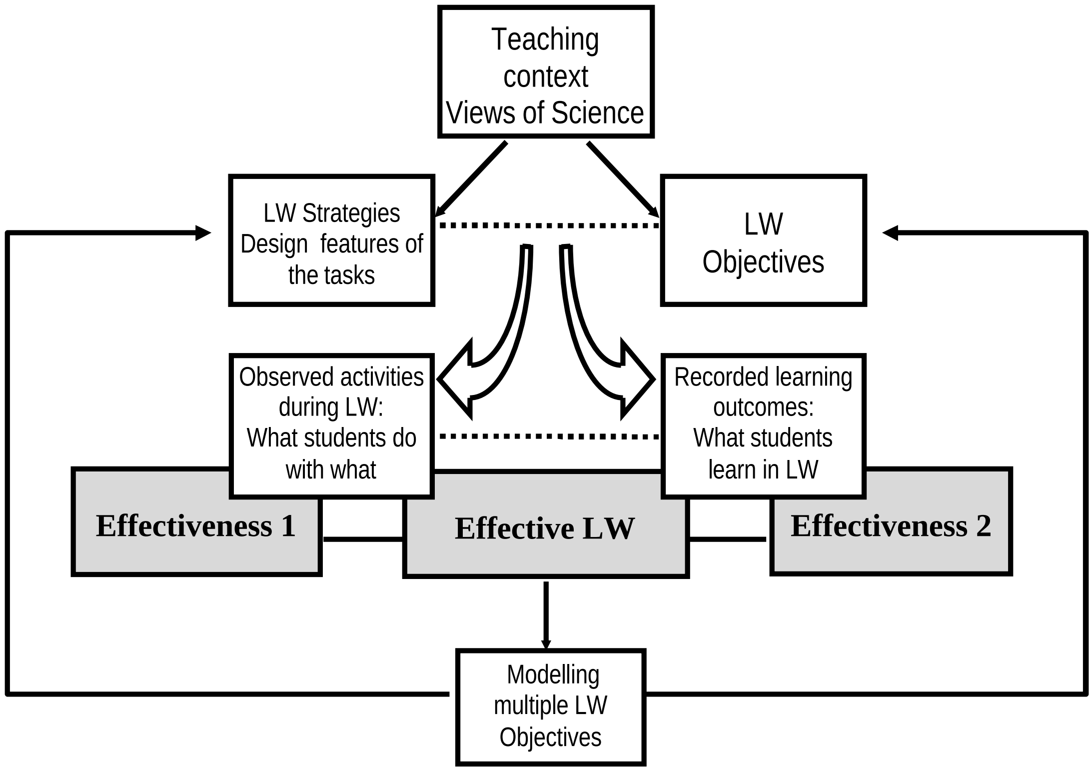
A classification of the case studies

Despite their diversity it was possible to classify the case studies into the following groups according to the dominant type of experimental work, which in turn made it possible to draw common findings:

- Labwork based upon small group work and hands-on experiments
- Labwork based upon the integrated use of new technologies
- Open-ended labwork
- Labwork addressing specific phases and based on various representations of labwork

The effectiveness of labwork

Two types of labwork effectiveness have been envisaged. ‘Effectiveness 1’ involves comparing students’ learning after labwork against expected learning objectives. ‘Effectiveness 2’ involves evaluating students’ actions and understandings during labwork against the actions that had been planned at the outset:



We suggest that the relationship between the use of conceptual, procedural and epistemological knowledge during labwork on the one hand, and learning outcomes after labwork on the other, is a complex one and we cannot envisage a simple causal relation between them. Besides, we suggest that a twofold effectiveness of the type described above is a very specific feature of the practical character of labwork among the various teaching activities in science education and, possibly, in other fields beyond science education.

Different types of labwork have been analysed using these concepts.

'TYPICAL' LABWORK BASED ON SMALL GROUP WORK AND HANDS-ON EXPERIMENTS

This type of labwork was investigated in six case studies. A general finding is that the majority of students’ time is spent upon manipulating apparatus and collecting data. In each case study, the major challenges for students involved conceptualising the theoretical background of laboratory activities rather than carrying out the procedures required in the laboratory. In effect, although teachers suggested that the learning objectives for each labwork activity involved making links between theoretical knowledge and material objects, students spent very little time on this (typically around 15%). This is perhaps unsurprising, as experts in the sciences develop action sequences for completing labwork tasks that do not in themselves involve drawing heavily upon conceptual knowledge.

In terms of Effectiveness 1, students need to be focused to spend more time ‘on task’ during labwork: in effect, they need to spend more time reflecting on links between conceptual knowledge on the one hand and their activities on the other. This could be achieved by the use of specific questions in labwork sheets, asking students to focus on particular theoretical aspects in the context of the data that are being collected.

Two laboratory based teaching sequences integrating presentation of theoretical information with discussion of qualitative data provided some promising results in terms of getting students to link theory with practice.

The place of prediction is currently poor. New types of teaching organisation are to be imagined to make predictive activities meaningful. The same can be said for calculation of orders of magnitude, which must not be an artificial exercise, but felt as indispensable to students.

LABWORK BASED ON INTEGRATED USE OF NEW TECHNOLOGY

Effects of new technology were analysed in nine case-studies. In these case-studies, the computer is used for data collection (MBL), for analysis and graphical representation of data, for modelbuilding (MBS), for simulation of a model, for demonstration of an interactive microscopic model, and for combinations of these types of uses. Video films are produced and used for demonstration of microscopic models, together with experiments.

Case study research served to illustrate the numerous positive uses of new technologies in terms of the effectiveness of labwork, as well as suggesting how some of the possible pitfalls might be avoided. Generally speaking, students did not experience difficulties in developing an appropriate level of competence in the use of the relevant software. However, strategies involving presenting students with algorithmic formulations about the use of software in a short time, as opposed to spending time developing a more principled understanding, resulted in fairly predictable problems of student autonomy during labwork activities. The potential of computers to display data graphically in real time proved a key feature in effectiveness in several case studies. The use of new technologies in presenting microscopic models and simulations was particularly effective at prompting students to focus upon links between conceptual knowledge and the behaviour of objects and events in the material world.

Generally speaking, using the computer for model building during labwork, stimulates students to talk more about the conceptual background of a specific lab situation than most other contexts of labwork.

OPEN-ENDED LABWORK

Five case studies focused on open-ended labwork. The contexts were various : projects in physics, mini-projects in biology to prepare students to projects carried out at the end of the year, field work in geology. These served to illustrate how open-ended labwork can be used to bring together both conceptual knowledge and knowledge of scientific procedures . The case studies also illustrated that a lot of objectives are implicitly pursued in open ended labwork, that are not easily made explicit. Furthermore, the case studies showed the importance of some sort of specific modeling of the processes of empirical investigation in order to teach about this explicitly.

This means that special attention must be given in teachers' education if they are to conduct open-ended activities.

CASE STUDIES INVOLVING SPECIFIC PHASES OF LABWORK AND BASED ON VARIOUS REPRESENTATIONS OF LABWORK

By this, we mean on the one hand labwork activities that focus upon a particular phase of an investigation (e.g. design, data collection, data handling), and on the other hand activities that focus on the representation of labwork in textbooks or CD-ROMs, for example. Again, it is apparent from the three corresponding case studies that it is particularly important to have some sort of explicit model of the investigation in mind in designing instructional sequences, or in writing accounts of labwork in published media.

In one case study, a teaching episode focusing upon data analysis was of limited effectiveness as the instructional materials used were not sufficiently focused upon data analysis and students did not therefore focus their actions clearly on data analysis [Effectiveness 1], and students appeared to have learnt little about data analysis from the activity [Effectiveness 2].

A similar teaching episode was more effective in promoting students' learning [Effectiveness 2] due to the use of a more explicit and targeted instructional approach [Effectiveness 1].

In a study of the portrayal of labwork in textbooks, many examples were noted which presented a stereotypical account of activities, neglecting the role of the scientist in making creative decisions about actions.

A model of the learning objectives for labwork

Based on the above analysis of the case studies, we propose three broad sets of learning objectives. The first two are the traditional objectives of promoting conceptual understanding and procedural competence. The third is rarely made explicit, and relates to more epistemological issues such as considering approaches to investigation, designing experiments, and processing data. Each of these potentially influences the other. In some cases, for example, laboratory procedures might be taught as a matter of routine whereas in other cases they might be taught with the aim of supporting concept learning. In the same way, measurement processing might be addressed as a routine algorithm, or alternatively with an epistemological emphasis upon links between knowledge claims and empirical evidence for those knowledge claims.

2 Policy implications

Research on teaching and learning does not lead directly to policy implications. Rather, those responsible for policy may select and draw upon relevant findings from research to inform their decisions. We believe that the findings from our research are relevant to policy in four areas:

2 . 1 The range of learning objectives in science education that can be addressed through labwork

Labwork could address a broader range of learning objectives than the range currently addressed. In particular, labwork rarely addresses epistemological objectives and teachers rarely make these objectives explicit when designing labwork activities, sequences of labwork or labwork sheets. Similarly, conceptual objectives, procedures to be learnt, data collection and processing are generally left implicit in the design of labwork. Specific conditions for successful learning have been established for each of these objectives. Findings from the project could be drawn upon, in the formulation of policy for labwork courses in the following areas:

- The range of learning objectives that could be used in labwork, especially the *'Map of the variety of labwork'*, the analysis of labwork sheets (§1.2) , the case studies.
- The difficulties likely to be experienced by students in meeting epistemological learning objectives, and in meeting conceptual and procedural learning objectives with a strong epistemological flavour (especially the *'Survey of students' images of science'*)
- The approaches that are most successful at achieving labwork that is effective at ensuring that students carry out activities as planned [Effectiveness 1] and that they achieve learning objectives [Effectiveness 2]
- The importance of teacher knowledge of epistemological aspects of science in labwork teaching (especially the *'Survey of teachers' images of science'*)

However, any planned modifications should take into account the important similarity of practice in labwork, suggesting that current practices are likely to be difficult to change.

2 . 2 The use of individual labwork activities to target specific learning objectives

Labwork could be better designed to address clearly defined learning objectives. Fewer objectives for each labwork session and a more coherent overall organisation of labwork ought to lead to improvements in student learning. Findings from the project could be drawn upon in the formulation of policy on objectives for labwork courses in the following areas:

- The range of objectives for labwork, from which more targeted sessions can be designed, might usefully be identified
- The methods of organisation and associated support materials that are most effective at ensuring that students carry out activities as planned and that they achieve learning objectives

2 . 3 Evaluating the effectiveness of labwork

The design of more effective targeted labwork will not be successful if it is not accompanied by the design of assessment. Findings from the project could be drawn upon in the formulation of policy concerning assessment. In particular research methods to evaluate effectiveness, as defined by the project, could renew assessment.

2 . 4 Teacher education

Teachers have a critical role in determining the effectiveness of labwork, as they are generally responsible for the design of labwork, for writing labwork sheets and for teaching during labwork sessions. Findings from the project could be drawn upon in the formulation of policy for teacher education, which can be thought as :

- Identifying the learning objectives least likely to be currently exploited and the range of them that could be used in labwork
- teaching the range of strategies possible to implement in labwork to provide effectiveness
- Identification of teaching and learning needs of teachers, in order for them to be able to address epistemological learning objectives with students
- Training teachers to specific guidance during labwork

Most of these implications suggest further directions of research.

3 Dissemination

During the project, the following dissemination activities have taken place:

- **24** scientific papers
- **32** publications in proceedings
- **30** communications in seminars and symposiums
- **7** theses

In addition, a dissemination meeting was organised in Thessaloniki, (Greece), in April 1998. Researchers from the LSE project presented findings and discussed policy implications with invited policymakers from the participating countries:

- France : Marie-Claire Méry
- Denmark : Ole Goldbech, Kirsten Woeldike
- Germany : Igmard Heber, Dieter Schumacher
- Great Britain : Bob Ponchaud, Carolyn Swain
- Greece : Christos Ragiadakos, Odysseas Valassiades
- Italy : Giunio Luzatto, Giancarlo Marcheggiano

- From DGXII of the EC : Godelieve van den Brande

Presentations of findings are planned at teachers' conferences and through journals targeted at teachers in all participating countries. In addition, special dissemination activities have been organised with a particular focus on teacher education.

Results from the LSE project will be disseminated within the academic community, through journal publications and the following conferences:

- Practical work in science education: the face of science in schools [Denmark, May 1998]
- First Greek conference on research in didactics of science and new technologies in education [Greece, May 1998]
- European Science Education Research Association [Germany, 1999]
- European Association for Research in Learning and Instruction [Sweden, 1999]

In summary, dissemination is planned towards the community of researchers, towards policy-makers and teachers.

3 . SCIENTIFIC DESCRIPTION OF THE PROJECT

RESULTS AND METHODOLOGY

In this part of the final report of the project ***'LABWORK IN SCIENCE EDUCATION'*** (hereafter referred to as 'LSE'), results are presented about three themes which were investigated through surveys. Through the first survey, an overview of the present practice in Europe has been made possible. Through the second, composed of a survey administered to students and another to teachers, the problem of images of science as linked to labwork, has been addressed. The third survey has allowed for the presentation of a picture of the teachers' intentions in the different countries involved. Each of these surveys are the subject of a chapter of part 3.

The different questionnaires, as used for data collection following piloting, can be found in working papers 2, 4, 5 and 6 respectively.

The last two chapters report the results obtained from 23 case-studies carried out in different contexts, for the three disciplines and the two teaching levels under study. The last chapter draws together results addressing the effectiveness of labwork.

Chapter 1

A tool of description : the 'map of the variety of labwork'

R. Millar, J.F. Le Maréchal, C. Buty

The ‘map of the variety of labwork’ (referred as the 'map of labwork') was developed at a relatively early stage of the LSE project, as a tool for use within the project and perhaps beyond it. It gives a taxonomy of labwork tasks providing a means of describing in detail any given labwork task. To develop this taxonomy, it was first necessary to specify what we mean by.

What do we mean by labwork?

The boundary between labwork and other science teaching/learning activities is not clear-cut and is, indeed, somewhat arbitrary. However despite the absence of a clear-cut line of demarcation, '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.
In almost all countries, science education, at some level, involves students and teachers working together in laboratories, or in the field. The term 'labwork' can include:
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.

Designing and evaluating labwork

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 1. 1.

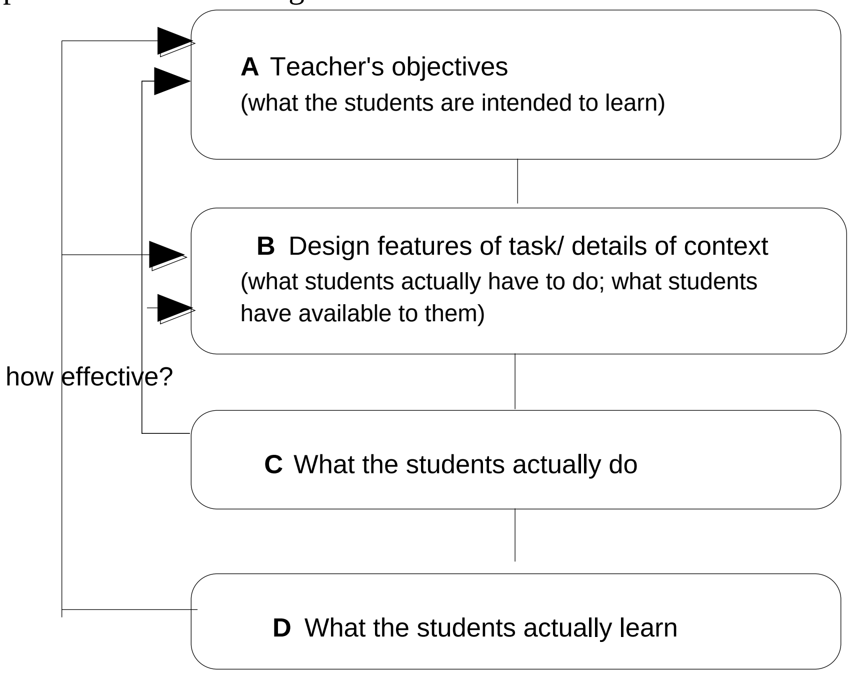


Figure 1 . 1: Design and evaluation of a science teaching/learning task

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 1 . 1): 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).

In designing the teaching/learning task, the teacher intends that the students will do something when given the task. So the model in Figure 1 . 1 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.

The model set out in Figure 1. 1 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 1 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 main dimensions of the map

The model of Figure 1 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.

These two main dimensions have 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. A characteristic 'profile' of each labwork task is provided.

Let us note that this map 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.

We have successfully used the map for the analysis of labwork sheets in biology, chemistry and physics for different European countries. It proved to be a valuable tool and a unifying concept of our whole project.

Chapter 2

SCIENCE TEACHING AND LABWORK PRACTICE

IN SEVERAL EUROPEAN COUNTRIES

Under the responsibility of COAST team (Lyon, France)

The survey about teaching and labwork practice (referred as 'current labwork practices' or survey 1) aims at giving an overview of the experimental aspects of science teaching in several European countries at the upper secondary school and at the two first years of university. In this perspective, we produced three studies :

The first study on the **science teaching organisation at the upper secondary school level** in several European countries gives the context in which sciences are taught, this teaching itself being a context for labwork activity. This study concerns the secondary school level to the extent that it can be organised, at least for the main features, at a large scale, usually the national one. At university level, it was too difficult to get an overview since the difference between universities of a same country can be too important for such a study be relevant.

The second study presents **specific aspects of the teachers' practice** related to labwork. The results are obtained from questionnaires dispatched to teachers of each country in the upper secondary school and in university (two first years).

The third study deals with an **analysis of the labwork sheets** frequently used at both levels of the upper secondary school and of the university. This analysis is based on the tool of description presented in chapter 1 *'the map of variety of labwork'* .

2 . 1 Science teaching organisation at the upper secondary school level in several European countries

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 Salamé, Carlo Tarsitani, Eugenio Torracca, Laurent Veillard, Stefan v. Aufschnaiter, Jean Winther

The countries that contributed to this study are Denmark, France, Germany, England, Greece, Italy, and Spain. In all these countries, science teaching may start at a very early stage of education. To get a better understanding of science teaching at the upper secondary school, we considered that it was helpful to know, even at a general level, how science is taught in primary and lower secondary schools.

- Situation before the upper secondary school level

At the primary level, it appears a rather common situation in all countries on several aspects:
- usually the primary teacher teaches all disciplines, including science;
- in general, the official curricula or instructions include science, most of the time as integrated science;
- the initial background of a great majority of the primary teachers is mainly arts and humanities and their scientific background is very limited.

Then, at primary school, sciences (integrated or not) are not much taught.
However, currently, some countries are trying through different activities (such as in-service teaching and the creation of new teaching material) to help primary teachers in introducing more science activities to their teaching.

At lower secondary school level, the situation can be very different from one country to another one, in particular from the points of view of contents, of the duration and of the assessment.
- The duration of science teaching for a given year can last from 480 hours (in some cases in Germany) to 150 hours (France, Greece, England).
- According to the countries, for the first three years the curriculum refers to integrated science (England and Spain) or to several scientific disciplines (Denmark, France, Germany and Greece). These disciplines are different according to the countries: for example in Denmark and Greece, geography is included in the group of scientific disciplines. Another dispersion appears: in some countries there is a discontinuity in science teaching from one year to the next, one subject discipline is taught one year only or with an interruption of one year. England seems to present the most regular and homogeneous science teaching over five consecutive years.
- This variety of teaching content makes difficult to situate effective labwork activity at a global level. In the case of Greece, students carry out no labwork, though teacher demonstrations are used during science lessons (in each discipline). The kind and amount of labwork in lower secondary in Germany depends on the teacher's decisions. By considering the assessment of experimental activity, it appears that this experimental aspect is particularly important in England and Wales (in Scotland too) and in Denmark. In England and Wales, for instance, in the assessment related to the stage from 11 to 14 years old (Key Stage 3), the weighting for the '*attainment target: Experimental and investigative science*' counts for 25% of the whole assessment. Obviously, this assessment

reinforces the role of labwork in science education. In Denmark, labwork is an essential part of all Science disciplines and the (optional) assessment for the Leaving Certificate in Physics/Chemistry is based on an experiment. In Germany, France Italy and Spain, this aspect is not assessed.

- The upper secondary school level

In the following, we only consider academic routes (in French : enseignement général) and not the case of vocational routes which is more diverse.

- **Science teaching organisation**

Three aspects were selected: the possible choices available to students to attend science teaching, the existence of a curriculum, the duration of science teaching according to the routes if any.

A basic aspect of science teaching organisation consists of the possible choices that students can make during the upper secondary school concerning the teaching content. Depending on the country, the type of choices is different. Two cases can happen:
- Choice of a whole set of an organised curriculum emphasising an orientation in science, or literature, or languages for example; in the following we call this set 'route'. In a given route, sub choices may be possible among some disciplines.
- Choice of disciplines.

The teaching organisation in England and Wales corresponds to the second case, the other countries are in the first case. Then it appears that, depending on the type of organisation, physics, chemistry, biology, geology are or are not taught to all students, the teaching content can or cannot be adapted to the students' orientation.

An aspect, common to all countries is that, for the scientific route in the countries where routes exist and in England and Wales, science is taught by separate subjects, biology, geology, chemistry, physics. In non-scientific routes, if any, it can be taught as integrated science.

Concerning the curriculum, we consider three groups of countries:
1 - Denmark, Greece and France where there is an official curriculum which specifies time duration for each subject;
2 - Germany and England where some criteria of assessment or some compulsory topics for each subject are given by a national body. In Germany, this plan is different in all the 16 different states, however a more general plan provides the same global orientation for all states (EPA: Einheitliche Prüfungsanforderungen).
3 - Italy and Spain are in an intermediate situation.

Concerning the allocation time for science teaching, roughly speaking according to the country and the student's choice at upper secondary school level, it can vary more than by twice as much, even in the scientific route (if any), at the last year of the secondary school the allocation time can vary a lot.

Let us also note that, depending on the country's tradition, different disciplines can be put together in the sense that they are systematically taught by a same teacher. In France, at the upper secondary school level, chemistry and physics are always taught by a same teacher, in Germany biology and chemistry are often taught by a same teacher.

- **Labwork in science teaching**

Three different approaches to the use of labwork in science teaching can be identified between the countries:

1 - In Denmark, in England and Wales, and in France where labwork is regularly done during teaching by small groups of students (pairs or groups of three or four), we can consider that labwork is compulsory. Moreover, in England and Wales labwork is assessed, and in France, inspectors check the balance between lecture courses and labwork. The frequency of labwork is about once a week for each discipline or group of disciplines.

2 - In Germany, labwork is possible, but is often not done. It is part of the general teaching time, but no special time is devoted for labwork. To a large extent, it depends on the individual teachers' decision.

3 - In Italy and Greece, labwork is done by groups of 2 to 4 pupils, is rare, only being found in experimental teaching. For example, in Greece, labwork is carried out in the 'Lycei' where special curricula have been adopted. Otherwise labwork depends on the teachers' initiative. In general, labwork rarely takes place, because of shortage of equipment, lack of laboratories and overloaded curricula. In Italy, in classical or scientific 'Lycei', labwork in class or in the lab is very rarely performed. It is more frequently performed in so-said professional Lycei. Spain is in an intermediate situation between 2 and 3.

In all countries where labwork is performed, the duration of the session is about 1 to 2.5 hours. The number of students in class, more often ranges from 20 to 35 (in Germany 6 to 25) and can be divided during labwork.

In academic route, labwork assessment is included to the final examination grade in England only. In Germany, there is a tradition in many schools to include demonstration experiments in the final examination ("Abitur"), e.g. in physics. In France, the assessment of labwork activity is currently being experimented.

In all countries, the teachers themselves carry out experiments in front of their pupils during lessons. The frequency of these experiments is up to the teachers.

In a nutshell, we can say that primary school science teaching is rather poor in almost all the countries, for similar reasons. In the lower secondary school the situation is extremely diverse according to the countries. In England, Italy and Spain the curriculum refers to 'science', and in the other countries it refers to subject disciplines. In particular, in these countries, a global view of science teaching does not show up. For example a subject discipline can be taught one year and not the year after.

2 . 2 Specific aspects of the teachers' practice related to labwork obtained from questionnaires

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, Jean Winther

A written questionnaire has been elaborated to learn more about teachers' practices in relation to labwork in the upper secondary school and in the university.
Such a questionnaire gives information at an intermediate level in the sense that it is at a more detailed level than that about the structure of the educational systems (Neville Postlethwaite, 1995; European reports, 1993, 94, 95) . These documents do not deal with the type of teacher's activity such as assessment or information given to the students. In the same time, it is less detailed than the information usually given by researchers in didactics who often need more specific information about the individual behaviours. We would say that, here, the information is an intermediate granularity level.

Five aspects were investigated:
- the types and the organisation of labwork activity including the relation between labwork and lecture (‘theory’ In England) and the type of information in the labwork sheet,
- the possible uses of computer during labwork,
- the labwork assessment that is taken into account and the importance of its assessment,
- the demonstrations,
- the teacher's preparation of labwork.

To give an overview of the results we first describe the sample, then we will discuss the similar features which appear to be rather important at the secondary and university levels. Then we focus on the main differences which appear either between the levels or between the countries. In this discussion in the case of secondary level we only take the countries where labwork can be carried out, that is Denmark, England, France, Germany; at university level Greece and Italy are included

- **Number and types of teachers who filled in the questionnaires**

The sample from each country is small. Moreover the respondents teachers are probably rather close to the research groups. Consequently, we do not consider the results as representative of each country. They only give a tendency. They also constitute a research tool in case of a larger scale survey.

Upper secondary school level

Table 1 gives the number of teachers in each country. Let us note that in Greece and Italy the questionnaires were given to the teachers who practice labwork; they are not at all representative of their country, since labwork is not a general practice. This is why, in the following, Greece and Italy are distinguished in the tables and figures (they are between parentheses).

	Denmark	England	France	Germany	[Greece]	[Italy]	Total
Biology	10	11	36	6	5	1	69
Chemistry	8	6		2	10	11	37
Physics	14	6		13	18	10	61
Physics + Chemistry			39				39
Biology + Chemistry				7		5	12
Total	32	23	75	28	33	27	218

Table 1: Number of teachers' answers by country and by discipline at secondary level

Table 1 shows the way in which the subject disciplines are put together: in France physics and chemistry are taught by a same teacher and in Germany biology and chemistry.

The teachers were asked for their experience in teaching and for the responsibility of the laboratory in their school. The results show that, in all countries, most of the teachers have a long experience more than 20 years except in Greece where, however, a majority still has between 10 and 20 years of experience.

University level

The questionnaires were given to university teachers in Denmark, England, France, Germany, Greece, and Italy. All of the teachers who filled the questionnaires are involved in the first or the second year of university. Depending on the university, the teaching organisation can be in module having different duration, year or semester for example. Then we asked teachers to choose a specific module and to use it as reference in the whole questionnaire. The number of teachers is given in Table 2.

	Denmark	England	France	Germany	Greece	Italy	Total
Biology	11	7	11	8	8	3	48
Chemistry	7	5	29	10	11		62
Geology			2		2		4
Physics	8	11	14	11	11	8	63
Physics + Chemistry	1						1
Biology + Chemistry						1	1
Total	27	23	56	29	32	12	179

Table 2: Number of teachers' answers by country and by discipline at university level

Concerning the teachers' experience, the results show that, even more than at secondary school level, most of the teachers who filled the questionnaires have a long experience of more than 20 years.

- **Main common features of labwork activity**

Type of labwork

As much at secondary school level as at university, the most frequent type of labwork is the same : students working in small groups, interacting with real material and/or equipment and following detailed instructions in a labwork sheet given by the teacher. Open-ended activities where students have a certain autonomy in the decisions are much less frequent particularly at secondary school level. The duration of this frequent type of labwork is limited in time, and is of the order of hours (1 to 5 hours); usually at university, it is longer than in secondary school but with the same order of magnitude. As to the project activity, it is currently rare, with a flexible duration, mainly at university level.

Type of information provided to the students for labwork

At secondary and university levels, similar types of information are provided to the students during labwork.

At secondary school level, results are similar for the disciplines and for the countries. The majority behaviour corresponds to a labwork sheet giving most of the time the questions which have to be studied and very frequently the steps to follow to carry out the experiments. They also give how to process data and how to present and discuss the results even if it is in a less extent. The theoretical context seems the aspect which is the most variable. It is given frequently in chemistry and most rarely in biology. In the case of France where physics and chemistry are taught by the same teacher it is rather rarely given.

At university, guidance on data processing and presentation or discussion of results are a little less important as in secondary school.

Assessment

Another common tendency concerns the aspects of students' activity taken into account in assessment. In all countries at secondary and university levels, the written report is the main object of the assessment.

Concerning the prominent aspects of the evaluation, teachers had to classify the following ones by order of importance:

- A precise description of the way the investigation was performed.
- Correct data acquisition.
- Creative/original ideas (e.g. in modifying the question or the apparatus).
- Detailed discussion of the quality of data (e.g. errors).
- Effective group work.
- Thorough interpretation of the experimental results.

It appears that at both levels, in most of the countries and for most of the discipline, *the thorough interpretation of the experimental results is the main aspect* the teachers claim as taken into account. Another main tendency concerns *the creative or original ideas*; this item is not very frequently the first teachers' choice. Also, the *effective group work* does not appear as very important, it is the only item for which the last choice is majority in several countries. Even if differences appear concerning the correct data acquisition and the detailed description of the quality of data, these aspects correspond either to a first choice or to an intermediate choice but very rarely as the last choice.

- **Differences in the main features of labwork activity**

The differences appear on two features: the link between lectures (theory) and labwork, and a tool for labwork: the computer.

Link between lectures (theory) and labwork

The main difference appearing between the secondary level and the university level concerns the link between the lectures (theory) and the labwork (see Figure 1, Figure 2).

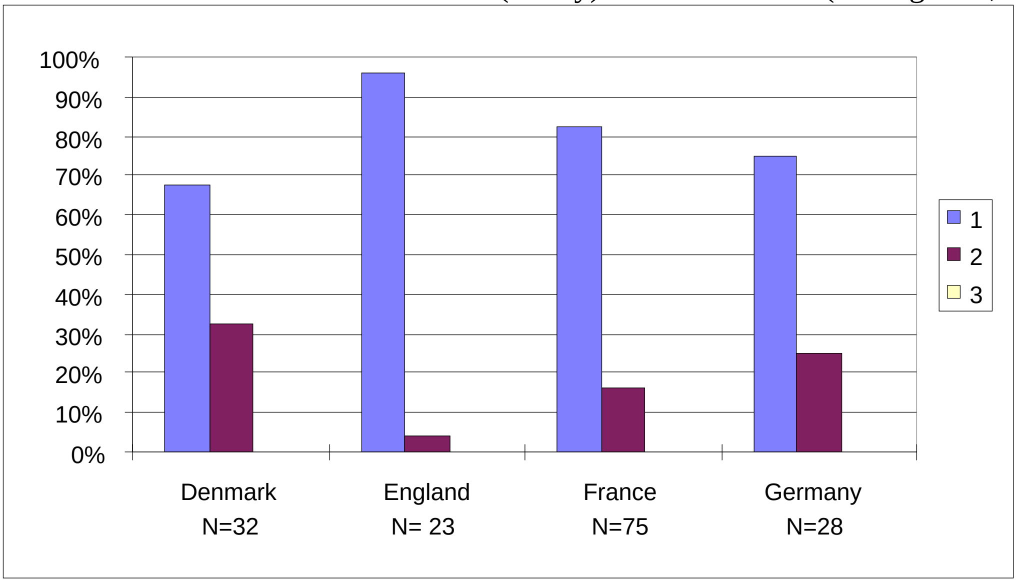


Figure 1: Link between lectures (theory) and labwork in upper secondary school
1: close relationship
2: close relationship but time gap for organisational reasons
3: no close relationship

At this level, there is no main difference between the countries, the link between labwork and lecture (theory) is strong, the item 'no close relationship' is never filled, and in most of the cases labwork and lecture are done at the same period of teaching.

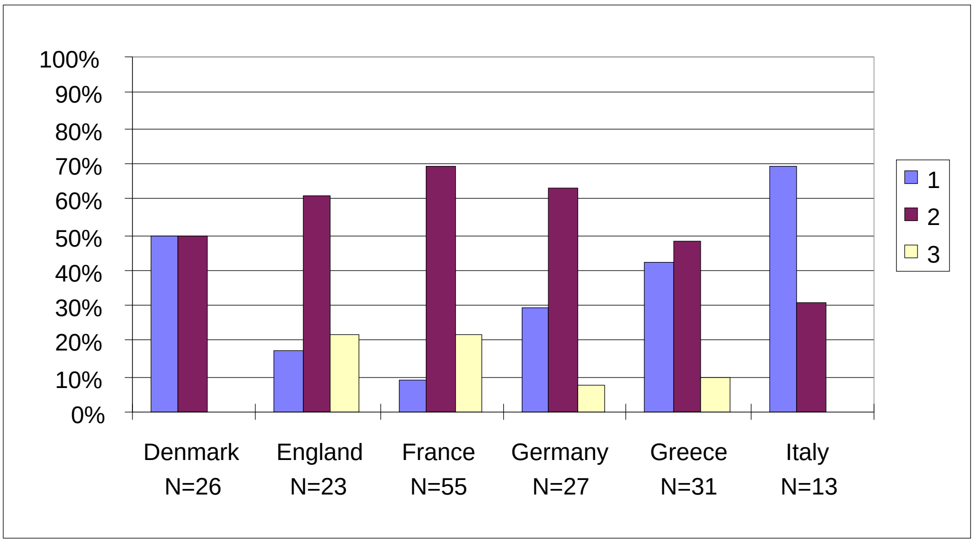


Figure 2: Links between labwork and lecture (theory) in university
1: close relationship
2: close relationship but time gap for organisational reasons
3: no close relationship

At the university level, the links between lecture and labwork appear rather flexible. In England, France, Germany and Greece, there are situations with no close relationship and the situation with a time gap seems frequent. On this organisational aspect of labwork, a strong difference appears between the secondary and university levels in the countries where there is regular labwork at the secondary level : in England, France, Germany, and in Denmark even if it is in a less extent, the relation between labwork and lecture is much weaker in university. Such a difference between the secondary and the university levels can be interpreted by general organisational aspects. At the secondary level, the same teacher has systematically in charge lecture and labwork, she or he can manage her/his teaching sequence and then the link between lecture and labwork. This situation does not happen at university. It is rather frequent that the teacher in charge of lectures is not the same for all labwork session ; then the organisation of sequence is depending on numerous conditions.

Uses of computer

Concerning the uses of the computer, there are several tendencies. At secondary school level, depending on the country and not on the discipline, the teachers can use a commercial interface (mainly in France) or a personal interface (mainly in England and Denmark). This difference disappears at university level.

It seems that the simulation is more often involved at secondary level than at university level even if it is not very frequent at secondary level. Computers are more frequently used to process data at all levels.
For the three countries where labwork is frequently practised at secondary school level : Denmark, France, England, the computer seems significantly used. It seems that at university level the use of computer is not more frequent (even less in France).

2 . 3 Analysis of labwork sheets at upper secondary school and university levels

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

This analysis was done with the contribution of the partners of each country involved in the project, in particular Dimitris Evagelinos, Dorte Hammelev, John Leach, Naoum Salamé, Florian Sander, Carlo Tarsitani

A priori, labwork sessions can be very different from one to another, learning objectives and the associate types of activities can vary even if, in all cases, experiments are involved. The question of knowing to what extent the usual labwork, in different European countries and in several disciplines, varies has been raised. To study such a question, it is necessary to characterise labwork activities. For that, the tool named *'the map of variety of labwork'*, elaborated during the first part of the project has been used (cf chapter 1). In this typology, three main aspects were taken : the learning objectives which the teacher has in mind in designing the activity ; what the student is expected to do - both with physical objects, and with ideas; and more pragmatic differences of duration, of the kind of equipment supplied, and so on. We used this typology to analyse labwork sheets selected by the research groups participating in the project as representative of usual and frequent labwork activity. The COAST group collected these analyses and treated them (with Excel) in order to highlight the main tendencies of similarity and differences of labwork at 2 levels, in the 3 disciplines and the seven contries under study.

At secondary level among the countries involved in the European project LSE only those where labwork correspond to a possible regular practice contributed, that is : Denmark, England, France, and Germany. At university level the countries involved are Denmark, England, France, Germany, Greece, and Italy.

Given the number of labsheets analysed (five of each type), this study gives the main tendencies. We take into account the results which are equal or more than 80% or equal or less than 20% of the sample ; moreover when the three disciplines together are very close to these limits, all of them are taken into account.

- Main labwork characteristics highlighted by labsheets

The duration is mainly about 80 minutes at secondary school, at university the duration is extended to 2 or 3 sessions.
Concerning the people with whom the students interact, at secondary school, at a quasi unanimity, students only interact with their teacher and with the other students carrying out the same labwork task. At university, students interact with two other types of people : more advanced students and in some cases others like technicians.

The specificity of the disciplines appears for a few aspects.
Physics is the discipline which has the stronger uniform characteristics. Whatever the countries and the levels, the labwork sheets ask to :

- use a laboratory device or arrangement
- observe a quantity.

In chemistry, most of the labwork sheets, particularly at secondary level, ask for using a laboratory procedure.
In biology, the strongest aspect is not a main tendency according to our criteria, it is like in chemistry “a laboratory procedure” but this activity is less present.
It can be said that the well-known specificity of the disciplines appears.

Concerning the degree of openness and the students’ or the teachers’ initiative, both at secondary school and university levels, the teacher plays a main role. The question to be addressed and the equipment to be used are specified by the teacher. For the other aspects (procedure, methods of handling data collected and interpretation of results), in physics the students have less initiative than in chemistry and in biology. Even for these aspects, particularly in physics and chemistry the teachers play the main role according to most of the labwork sheets.

In the following aspects, the typology of the map not only shows what usually the labwork activities are, but also what they are not.

At secondary school the main learning objectives are :
- in all disciplines, to identify objects and phenomena and become familiar to them
- in physics only, which is strongly different from the other disciplines, to learn a relationship.

At secondary school the main learning objectives are not :
- in all disciplines, to learn a theory/model
- in all disciplines, but less in biology, to learn how to plan an investigation to address a specific question or problem.

At university level, the main learning objectives are :
- for chemistry, how to carry out a standard procedure
- for physics, how to process data.

At university level, the main learning objectives are not :
- mainly in chemistry and biology to learn a theory/model, (it is still not important in physics);
- how to plan an investigation to address a specific question or problem.

Concerning the design feature of tasks, at secondary school,

- the sources of information in all disciplines are:
  - inside the laboratory

- the sources of information in all disciplines are not:
  - outside the laboratory
  - from computer or CD-ROM
  - from text.

Concerning what the students are intended to do with objects and observables, at secondary school and university levels,

- the students are supposed :
  - to use a laboratory device in physics or a laboratory procedure in chemistry and in a less extent in biology ;
  - to observe a quantity in physics ;

• the students are not supposed :
  - to present or display something,
  - to make an object, or a material (except in chemistry at university level)
  - to observe a material (except in chemistry at university level).

Concerning what students are intended to do with ideas, at secondary school level,

• the students have to:
  - direct report of observation
  - only in physics, explore relation between physical quantities;

• the students do not have to:
  - explore relation between objects
  - 'invent' a new concept (physical quantity, or entity)
  - test a prediction from a guess, a law or a theory
  - account for observations by proposing a theory
  - choose between two (or more) explanations.

At university level, the students have to :

- only in physics, explore relation between physical quantities
- only in physics, determine the value of a quantity which is not measured directly
- only in physics, account for observations in terms of a given law

At university level, the students do not have to :

- identify a pattern
- explore relation between objects
- 'invent' a new concept (physical quantity, or entity)
- test a prediction from a guess for all disciplines and, only in chemistry and biology to test a prediction from a law or a theory
- account for observations by proposing a theory
- choose between two (or more) explanations.

- Conclusions

At the level of granularity of our analysis, that is the general teachers’ practice and not the individual differences, the similarity both between disciplines and countries concerning usual labwork activity is very important, and more than it could be expected taking into account the differences of the educational systems of each country. Some very important activities in the practice of these experimental disciplines would not be involved in the usual labwork. For example if, in physics learning to establish relations or in chemistry learning to use a standard procedure, is very common, it seems very rare that labwork activity involves “to do account for observations in terms of law or theory” or involves “to choose between explanations”.

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Chapter 3

The surveys ' Teachers and students' Images of science'

INTRODUCTION

Marie-Geneviève Séré

It was felt from the outset of the project that an important outcome of science education at school and university is the images of science that students develop, even though this is not necessarily stated as an explicit aim of science education. It is not, however, easy to identify the origins and evolution of such images of science. During the project, two aspects were addressed. The first one was an attempt to understand the images of science that students draw upon during labwork. This was investigated through a survey administered to students in several countries under the responsibility of the GB group.

The second aspect made links between students' images of science and explicit teaching about the nature of science. This was addressed through a survey which was administered and piloted in Italy, and to a lesser extent in France, under the responsibility of the Italian group. The corresponding diagnostic questions between these two studies are rather different, which is hardly surprising given that they were developed by two groups to address different research questions, as described below.

Data collection on both surveys started in the same way, as the intention was to write diagnostic questions following some piloting. Some questions focused upon situations in which the context was elaborated in detail, whereas on other questions the context was barely elaborated. It is necessary to take into account in analysis the difference between a reaction to a real laboratory situation, a response to a survey question in which the context is elaborated, and an answer to a question in which the context is not elaborated with the result that respondents will probably draw upon different contexts in answering. This issue was addressed in different ways, such as writing different types of questions, the comprehensibility of which are checked through piloting as will be described. Furthermore, the difficulties of generalising from responses to very specific situations are recognised, as can be seen from the recommendations stemming from the study.

It is worth noting that the main intention was not to compare results between countries, given the constraints on sampling. The only relevant comparison is between the national contexts in which the research was conducted. This was revealed through a long process of discussion about diagnostic questions, during which some specific views could be identified. For instance, for the students' survey, there was an agreement among the participating groups that measurement, data processing and data interpretations are a part of labwork as well as of the scientific activity. So, from the results, a new light could be shed on the dependence of data processing from epistemology. The results will also allow to discuss the relevance of searching for an individual underlying epistemology to interpret students' attitudes and answers. The preoccupation for the teachers' survey was rather to address the problem of the respective links of theory and experiment. This is more directly the issue of epistemology, which, in this view, is considered as a subject matter to be taught. This survey allowed to make available a research tool on this subject.

3 . 1 Survey 'students' images of science

as they relate to labwork learning

John Leach

3 . 1 . 1 Management and realisation of the work

This was carried out under the responsibility of John Leach and colleagues in the GB group. Data were ultimately collected in 5 of the 6 countries participating in the LSE project. The team responsible for taking the work forward in these countries was John Leach, Robin Millar and Jim Ryder (GB), Marie-Geneviève Séré (France), Dorte Hammelev (Denmark), Hans Niedderer (Germany), and Vasilis Tselfes (Greece).

During the LSE project, a number of other researchers were centrally involved in meetings designed to take this study forward; these people were Milena Bandiera, the late Rosalind Driver, Dimitris Evangelinos, Dorte Hammelev, Helge Kuhdal, Jenny Lewis, Jean-François le Marechal, Jonathan Osborne, Dimitris Psillos, Carlo Tarsitani, Andrée Tiberghien, Eugenio Torracca and Jean Winther.

3 . 1 . 2 Aims

This study was designed to provide information about the images of science drawn upon by science students during labwork. By ‘images of science’ we mean the profile of ideas about the epistemology and sociology of science used by individuals in specific contexts for specific purposes. In the case of labwork, students draw upon images of science to explain the purposes of empirical investigation, relationships between data and knowledge claims, and relationships between knowledge claims and experimental design, analysis and interpretation of data. As individuals are viewed as having a number of images of science that might be deployed in a given situation, no attempt was made to classify individual students as thinking in a particular way. Rather, findings from the study have been used to identify ways of thinking used by large numbers of students in a variety of situations.

What have ‘images of science’ got to do with labwork? To answer this question, we need to ask ourselves about the purposes of labwork itself. During the LSE project a conceptual exercise was undertaken to identify the different purposes of labwork (*Working Paper 1*). The purposes identified can be grouped into three broad areas:

- developing students’ knowledge of the behaviour of the natural world, helping them to make links between the world of natural phenomena and the world of theoretical descriptions and explanations of phenomena, and thereby developing their understanding of scientific concepts;
- developing students’ understanding of how scientists undertake empirical investigations to address a question or problem of interest;
- developing students’ ability to use standard laboratory instruments and procedures in undertaking investigations

The first of these areas is mainly concerned with teaching scientific *content* (i.e. the laws, theories, concepts etc. that constitute scientific knowledge). By contrast, the main concern of the second two areas relates more to teaching about the *methods* used by scientists in empirical work. A further aim of some labwork relates to teaching about social and institutional processes used in scientific communities

Labwork with each of these aims involves students in drawing upon understandings of the nature of empirical data, the nature of scientific knowledge claims, the ways in which knowledge claims and data are related, the purposes of using techniques, procedures and instruments, and so on. Many students in teaching laboratories often work with knowledge claims already agreed as reliable within the scientific community. For example, they may be involved in work to illustrate accepted theories or to apply accepted theory in specific contexts. Their ideas about how that knowledge came to be viewed as reliable may well influence their labwork. For all these reasons, participation in labwork involves students in drawing upon epistemological understanding.

A number of studies of students' images of science have been reported in the literature. However, few of these relate either to students of upper secondary and university age or to the images of science that students might draw upon during labwork. The study reported in this paper therefore had two major purposes:

- To review existing research on students' images of science, and to consider the nature of labwork, in order to propose hypotheses linking students' images of science with their learning during labwork.

- To generate preliminary baseline data about upper secondary and university science students' images of science, in areas hypothesised as being relevant to labwork learning.

3 . 1 . 3 Methods used

A set of 9 hypotheses were generated in order to identify potential links between labwork as an activity undertaken by science students, and images of science. These hypotheses were then used to identify research questions about the images of science that students might draw upon during labwork, and potential implications of those images of science for students' learning during labwork.

In order to collect data from a multilingual sample, a closed-response written survey was used. A set of five diagnostic questions (termed Probes) were produced and administered to students. This involved producing multilingual versions of each Probe, together with a coding scheme based on extensive piloting.

Two of these Probes were written to present students with generalised statements about the role of knowledge claims and data in experimental work. The other three were written to present students with vignettes of empirical investigations, to find out how students interpreted experimental design and data collection, analysis and interpretation. Closed response statements were written following extensive piloting in five countries.

Some of the research questions were not investigated. In some cases, this was because the questions were thought to be more appropriate for younger learners of science (e.g. RQ4 and 6). In other cases, we were unable to design Probes to investigate the research question (e.g. RQ8).

The hypotheses and research questions are shown in Table 3, together with the names of research Probes used to investigate the research questions:

TABLE 1: HYPOTHESES AND RESEARCH QUESTIONS ABOUT STUDENTS' IMAGES OF SCIENCE AND LABWORK

Hypothesis	*Research question and Probe*
H1: Many students consider that, with good enough apparatus and enough care, it is possible to make a perfect measurement of a quantity. That is, they assume that measurement can be perfectly *accurate*. Others consider that any measurement is subject to some uncertainty, and so obtaining accurate values is problematic.	RQ1: Do students see measured data as a 'perfect' copy of reality, or do they view measured data as being subject to some uncertainty? What do they see as the sources of uncertainty in measured data? How do they overcome these uncertainties and select a value? Do they recognise the difference between *accuracy* and *precision*? *Probes: Differences in Values from Measurement, Surprising Results*
H2: Some students do not recognise the kinds of empirical evidence on which scientific knowledge claims are based. In the case of measured data, they think that it is only possible to judge the quality of a measurement from a knowledge of the 'true' value, given by an authority source. That is, they do not recognise that decisions about *precision* can be made from sets of measurements. Other students think it is possible to judge the 'quality' of measured data from a set of repeated measurements. That is, they reason that data sets can be evaluated in their own terms to make decisions about accuracy and precision.	RQ2: Do students believe that the only way to judge the quality of a measurement is from a known 'true' result, or do they believe that the quality of a measurement can be judged from a set of repeated measurements? If so, do they distinguish the *accuracy* and *precision* of measured values? *Probe: Differences in Values from Measurement*
H3: Many students see data reduction and presentation as a process of *summarising* data and see procedures like joining data points on a graph, drawing a 'best fit' straight lines, or drawing smooth curves as *routine heuristics* **-** that is, they see the process as independent of theory. They believe that there are standard techniques for arriving at 'perfect' descriptions of data. Others see such procedures as a process of proposing *tentative hypotheses about a relation between variables.* That is, they believe that experimenters and computers make decisions during data reduction and presentation according to existing models.	RQ3: When working with data sets, do students see procedures like joining data points with lines of 'best fit' or smooth curves as routine heuristics, or alternatively as a process of proposing tentative hypotheses? *Probe: Interpreting Data*
H4: Some students think that the logic of proof and falsification is symmetrical: data that logically support a law 'prove' the law, in the same way that data that do not support a law logically falsify it.	RQ4: Do students recognise the logical distinction between proof and falsification when handling empirical data? *Not investigated*

H5: Some students think that most/all questions about natural phenomena are answerable by collecting observational data and looking for correlation. Explanatory theories (models) ‘emerge’ from this data in a logical way: there is only one possible interpretation. Other students think that prior models (theories, hypotheses) influence decisions about what data to collect and how it is interpreted, and that observation and measurement are intended to test these models. Again, the testing is based on logic: only one interpretation is possible. Others think that a data base is first collected on the basis of embryonic theories and hypotheses - more robust models are then proposed as conjecture to account for existing, and anticipated data. Then predictions derived from these may be tested by planned observations or experiments, but more than one interpretation is possible due to the conjectural nature of theory.	RQ5: Do students think that scientific theories ‘emerge’ from data, or do they think of scientific theories and data as being related in a more complex way? If so, how do they think that scientific theories and data are related? In particular, do they think that a given experiment is open to more than one interpretation? *Probe: Theory and Data in Scientists’ Work, The nature of Scientific Results, Surprising Results*
H6: Many students see practical activities in the teaching lab as exercises to reproduce well-known results, or to illustrate important theories/models, no matter how the task is actually presented by the teacher! They do not recognise the labwork as an exercise in ‘finding out’. Other students recognise that some labwork activities have an investigative component: they involve ‘finding out’. Amongst these students, some assume that knowledge claims can be ‘proved’ or ‘disproved’ by a single planned intervention, whereas others assume that the process of investigation involves a sequence of interventions which may be modified in the light of experience.	RQ6: Do students recognise the purpose of particular labwork tasks as involving ‘finding out’? *Not investigated*
H7: Some students believe that scientific theories are ‘perfect’ copies of natural phenomena: there is a one-to-one correspondence between theory and ‘reality’. Such students believe that it is a straightforward empirical process to show that scientific theories are ‘true’. Others believe that theories are model-like, and do not correspond perfectly to reality. However, such students still believe that it is a straightforward empirical process to show that scientific theories are ‘true’. Others believe that theories are model-like, and this means that it is NOT a straightforward process to show that a scientific theory is ‘true’.	RQ7: Do students think that scientific theories are conjectural in nature, or do they think that theories are always constituted in terms of observable entities? *Not investigated*
H8: Some students do not recognise the different levels, types and purposes of explanation that are used in science. [Examples: teleological, causal, descriptive, model-based..].	RQ8: Are students able to distinguish between teleological, descriptive and model-based explanations of natural phenomena? *Not investigated*
H9: Some students think that all the knowledge claims addressed in science are of the same status. They do not recognise the authority of the scientific community in the validation of public knowledge. Others recognise that some knowledge claims are widely accepted within the scientific community, whereas others are still the subject of investigation and debate.	RQ9: Do students recognise that different courses of action are appropriate in scientific investigations according to the status of the scientific knowledge claim under investigation? *Probe: Surprising Results*

3 . 1 . 4 Sampling

Data were collected from a sample of 432 upper secondary school students and 229 university students. In each country, the sample was constructed to be as representative as possible of students in academic streams at the given level.

The sample cannot be viewed as nationally representative, however. It is more appropriate to view this study as providing insights into the sorts of images of science that might well be drawn upon by students during their labwork learning, than giving quantitative indications about the likely representation of images of science within and between populations. A small number of teachers completed the Probes, in order to provide some information from which conclusions could be made about the face validity of the Probes. Details of the sample are given in Table 4:

TABLE 2 : DETAILS OF THE SAMPLE USED

COUNTRY	*UPPER SECONDARY STUDENTS* TOTAL	*Phys.*	*Chem.*	*Biol.*	*UNIVERSITY STUDENTS* TOTAL	*Phys.*	*Chem.*	*Biol.*	*TEACHERS* [Upper secondary	*University*]
Denmark [1]	219	*88*	*47*	*84*	0	0	0	0	39	*0*
France [2]	103	103	103	103	70 [4]				0	*0*
Germany [3]	55	15	24	16	84	32	29	23	0	*0*
Great Britain [3]	82	33	38	31	85	26	25	34	2	*4*
Greece [3]	78				60	22	15	23	0	*0*

Total upper secondary students for *Differences in Values from Measurement* and *Surprising Results*: 422
Total upper secondary students for *Theory and Data in Scientists Work, The Nature of Scientific Results* and *Interpreting Data*: 432

[1] In the Danish sample, each respondent only answered a subset of the questions.
[2] All science stream students study each science subject in France.
[3] Many students in these samples studied more than one science subject, but not necessarily all three.
[4] French university students study some physics, chemistry and biology during the first two years, even though their courses ultimately lead to different specialisms. The sample has been constructed to include students working towards different specialisms.

3 . 1 . 5 Findings

Students' responses to the Probes are reported mainly as frequency counts of numbers of responses to multiple choice questions. In cases where students selected more than one response all responses were coded. Some percentages therefore total more than 100. In other cases, not all students responded to each part of a question and percentages therefore total less than 100.

Differences in Values from Measurement

In this Probe, students were presented with sets of repeat measurements of the mass of a given volume of oil. They were asked to state a result for the mass of the oil from the available data, and to comment upon the confidence that could be ascribed to the value. Table 5 shows the number of students agreeing with various statements about the confidence that could be ascribed to a difference of 0.2g in the mass of two different oils, based on measurements of 5 aliquots taken from a sample. The data are expressed as frequency counts as a percentage of the sample of students:

TABLE 3: IS THE MASS OF 100 cm3 SOYA OIL DIFFERENT FROM THE MASS OF 100 cm3 OLIVE OIL?

	Upper secondary	University physics	University chemistry	University biology	French University	**TOTAL: Uni.**
Agree with A: the mass of olive oil is greater, as the average is greater	29	13	33	28	16	22
Agree with B: There is no difference, because the range of measurements is much greater than the difference between averages	8	10	3	9	6	7
Agree with C: No difference, because 94.1 measured by both groups	4	1	0	5	1	2
Agree with D: We cannot be sure, because the range of measurements is much greater than the difference between averages	47	71	68	26	53	62
Agree with E: We cannot be sure, because 94.1 measured by both groups	17	7	6	10	16	10

These results were typical of those obtained elsewhere on the Probe. Most students in the sample appeared able to follow some sort of algorithm to select a value from a set of measured data. For some students, this algorithm appeared to be underpinned by explicit understanding of the implications of spread of data for the confidence that can be ascribed to an estimate. Around 40 - 60% of students in the sample were in this category, with about 10% more students at the university level responding in this way than the upper secondary level. However, for many students, the use of algorithms in selecting values did not appear to be underpinned by an explicit understanding of the implications of spread for confidence. About 20 - 35% of students in the sample were in this category, with little evidence of difference between the university and school levels.

Between about 5 and 15% of students in the sample appeared to hold a view that ‘real’ values correspond to measured data (for example, those selecting statement E above. Although the numbers are small, marginally fewer university students appeared to reason in this way.

Looking at data from the Probe as a whole, there was some evidence university biology students have less appreciation of the implications of spread of data for the confidence that can be attributed to estimates of values, and that biology students are marginally more likely to hold the view that ‘real’ values should correspond to measured data. This is surprising, in that much data handled in biology takes the form of frequency counts (e.g. population data in ecology, assay results in biochemistry), and this data is often subject to some form of statistical analysis in order to draw conclusions. A possible curriculum goal for labwork in all three sciences, and particularly biology, might therefore be to teach students about confidence, accuracy and precision in data handling.

Theory and Data in Scientists’ Work

In this Probe, students were presented with 7 pairs of statements about the rationale used by scientists in planning experiments, and in collecting and analysing data. The pairs of statements were written to express opposite viewpoints. Students had to state, on a scale of 1 to 5, their agreement or disagreement with the statements. Students' responses are summarised in Table 4, as frequency counts as a percentage of the sample:

TABLE 4: FREQUENCY COUNTS OF RESPONSES ON PAIRED STATEMENTS

Statement A	Agree with A	No strong view	Agree with B	*Statement B*
The design of an experiment is dependent on theory about the thing that is being investigated.	***53*** **57**	***21*** **9**	***24*** **22**	An experiment is designed to see what happens, and does not depend on theory about the thing that is being investigated.
Scientists' ideas and theories influence their planning of data collection in experiments.	***59*** **70**	***16*** **12**	***24*** **15**	Scientists put their ideas and theories to one side when they are planning data collection in experiments.
In analysing a given data set, it is quite reasonable for different scientists to use different theoretical perspectives.	***78*** **83**	***9*** **7**	***11*** **8**	In analysing a given data set, there is only one theoretical perspective which it is reasonable for scientists to use.
Scientists interpret data without being influenced by their theoretical assumptions.	***19*** **19**	***17*** **14**	***62*** **65**	Scientists' theoretical assumptions influence their interpretation of data.
One data set always leads to one conclusion.	***15*** **7**	***13*** **16**	***70*** **76**	Different conclusions can legitimately result from the same data.
Scientists plan their data analysis based on the ideas and theories that they had when designing the experiment.	***67*** **77**	***18*** **12**	***15*** **8**	Scientists plan their data analysis without reference to the theories that they may have had when designing the experiment.
It is *not always* possible to tell which is the most powerful of two competing theories, no matter how much data are available.	***54*** **64**	***23*** **3**	***23*** **21**	It is *always* possible to tell which is the most powerful of two competing theories if enough data are available.

Upper secondary total
University total

Students' responses being widely spread between categories, we have concerns about the use of decontextualised questions for eliciting the images of science that might be drawn upon by students during labwork. In particular, we are aware that we have no idea of the type of experiment, data or theory that students have in mind when answering the question.

Data collected on this probe suggest that most upper secondary students think of data and theory as being related in designing experiments, analysing data and drawing conclusions, and that even more university students think in these terms

Generally speaking, more university students selected the statements planned as epistemologically sophisticated, than upper secondary students. Differences between students from different subject backgrounds were small.

Surprising Results

Students were presented with two scenarios involving data collection. In the first case, science students were collecting data about the production of starch in plant leaves kept in the light or in the dark. In the second case, a correlation between the proximity of children to chemical plants and the occurrence of leukaemia was being investigated. In both scenarios, contradictory claims were made on the basis of data that had been collected. Students were presented with statements as to what should be done next by the science teacher, or the government body commissioning the research. They had to state whether they agreed with the course of action, disagreed, or were not sure of their opinion. They also had to suggest the course of action that they thought was *most* appropriate. Students' responses as to which course of action is most appropriate, expressed as percentages of the sample, are given in Tables 5 and 6:

TABLE 5 : COURSES OF ACTION BY TEACHER AND STUDENTS IN AN EXPERIMENT ON STARCH PRODUCTION IDENTIFIED AS MOST APPROPRIATE BY STUDENTS IN SAMPLE

	Upper secondary Ag. Dis. ns	**UNI. TOTAL**
A: Repeat the experiment, as result will become clear	20	9
B: Repeat: discrepancies are due to faulty materials	19	14
C: Explain the unexpected results as error/ anomaly	14	7
D: State the accepted explanation, use it to explain unexpected results	25	31
E: Overturn the accepted conclusion (that sunlight is required for starch production)	0	0
F: State that standard theory is over-simplified	16	13

TABLE 6 : COURSES OF ACTION BY COMMISSIONERS OF RESEARCH INTO LEUKAEMIA CLUSTERS AND SITING OF CHEMICAL PLANTS

	Upper secondary Ag. Dis. ns	**UNI: TOTALS**
A: Ask groups to repeat studies, to reach a firm conclusion	6	3
B: Ask other scientists to check results, to reach a firm conclusion	13	8
C: Commission more data collection: an answer will become clear	12	13
D: Decide that the risk is great, and close the plant	5	2
E: Conclude that the risk is small, and allow the plant to continue	1	2
F: Look for factors other than chemical plant	41	31
G: Commission theoretical work	16	13

On the open response pilot to this question, two main positions about the place of data and theory in guiding the teacher's actions following the starch production experiment were stated by students in their own words. The first of these referred to collecting quality data from which an answer would logically become apparent (summarised in statements A, B, C and E). Around 50% of students at both upper secondary and university level agreed with these statements. The second main position stated in the pilot study referred to the use of theory in guiding interpretations of data (summarised by statements D and F). Between about 40 and 70% of students at each level agreed with these statements. When stating which statement was preferred, about 53% of upper secondary students and 30% of university students selected a data-focused statement, compared to 41% and 44% respectively selecting a statement involving the role of theory. A large number of university students (26%) did not select a preferred statement, however.

It is not straightforward to interpret what students' responses to this Probe mean. For example, statement 'A' was written to convey the view that if data are collected the result will *inevitably* become clear. However, it may have been interpreted as meaning that data should help to clarify the result. Depending on which interpretation of the statement is made, responses would be different. Having said that, it appears highly likely that large numbers of students both at the upper secondary and university levels focus upon data much more strongly than theory in interpreting results in school laboratory work.

Of the statements presented to students about what should be done in the leukaemia cluster study, A, B, C, D and E are all data focused, whereas statements F and G involve drawing upon theory to inform interpretation. Around 60% of students at each level agreed with statements A, B and C, with marginally more upper secondary students than university students. Most students (73 - 92%) agreed with statements F and G, though 17% of upper secondary students and 14% of university students explicitly disagreed with statement G ('commission theoretical work'). Statements D and E argued that decisions about risk could be decided on the basis of available data: between 10 and 17% of students at each level agreed with these statements.

37% of upper secondary students and 28% of university students selected a data-focused statement as their preferred statement, and 57% of upper secondary students and 44% of university students selected a statement involving theory. However, 28% of university students did not select a preferred statement.

Taken together, the above evidence suggests that many students both at upper secondary and university level may well take a data-focused view in interpreting empirical data. It is perhaps not surprising that more students agreed with statements involving theory relating to leukaemia clusters, where the scientific knowledge claim under investigation is controversial, than agreeing with statements involving theory about starch production where the knowledge claim in question is well established.

Analysing Data

Students were presented with a vignette of an academic conference in which groups of scientists were debating the interpretation of a data set. Two different theoretical models were being used to account for a given set of data. Students were presented with statements about the different interpretations of the data. Some of these statements suggested various conclusions that might be drawn on the basis of existing data, others suggested that the underlying theories themselves needed to be examined, and one statement suggested that there is no rational basis for choosing between the different interpretations. In each case, students had to state whether they agreed with the statement or disagreed with it, or whether they were not sure of their opinion. Students were then presented with further statements about possible courses of action that might be followed by the scientists to resolve the difference in interpretation. The students had to state their viewpoint on each statement.

Table 7 shows students' responses to statements about how lines of best fit might be drawn. Responses are given as frequency counts as a percentage of the sample:

TABLE 7: STUDENTS' SUGGESTIONS AS TO RELATIONSHIPS THAT MIGHT BE DRAWN BETWEEN MEASURED DATA POINTS

	Upper secondary	**Uni. total**
DidaScO group: Draw a line joining each of the points. We are confident about each measurement, so this is the best approach.	4	3
BREM group: Consider which model could best be used to explain this data set. Once the best model has been agreed upon, a line can then be drawn through the data points.	38	42
TESME group: Use a computer to generate the best curved line through the data pints. This is the best approach.	22	25
ROMA group: There is no way of knowing which is the best way to join the data pints. It is up to individual scientists to make up their own minds.	21	16
I don't agree with any group! I have written my opinion below.	9	10

The DidaScO and TESME statements were written to summarise strongly data-focused positions. In practice, few students selected the DidaScO position, though 26% of upper secondary students and 28% of university students selected either the DidaScO or TESME position. It was surprising that so many students appeared to assume that computers could be used to distinguish between two different interpretations of a data set, without referring to the underlying models that might be used in programming the computer. The BREM statement was written to summarise a position involving both theory and data. 38% of upper secondary students and 42% of university students selected this statement. The ROMA statement was written to summarise a radical relativist position, and was selected by 21% of upper secondary students and 16% of university students.

Similar patterns of responses were found elsewhere on the Probe.

Taken together, the evidence presented above seems to suggest that up to a third of upper secondary and university level science students in the sample tend to focus exclusively upon data at the expense of underlying theory, in interpreting findings from empirical investigations. There is also evidence that between 10 and 20% of students in the sample appear to hold the extreme relativist view that it is not possible to distinguish between different interpretations of data. Generally speaking, more university students than upper secondary students selected and agreed with statements mentioning explicitly links between theory and data in the interpretation of empirical work. For example, 28% of upper secondary students, compared to 40% of university students selected statement C on part 1, 41% and 52% respectively agreed with statement D on part 2, and 38% and 42% respectively selected the BREM group's statement on part 3. There was no strong evidence for subject-related differences in responses to this Probe.

The role of context

Individual students' responses on decontextualised questions were compared with their responses to questions with specified contexts, to find out whether some students have an epistemological predisposition to drawing upon particular images of science. For example, it might be expected that students who made data-focused responses on the Theory and Data in Scientists' Work probe would also do so on Probes with a similar focus (e.g. The Nature of Scientific Results, Interpreting Data). Only 8 students in the whole population answered consistently across these Probes. This suggests that questions such as the Probes used in this study cannot be used to make predictions about the likely behaviour of individual students during labwork. Rather, sets of responses from students give an indication of the range and variety of images of science that might be represented within a population.

3 . 1 . 6 Recommendations

Earlier in this report it was suggested that findings from this study could be used in identifying possible curricular goals for labwork at the upper secondary and university levels, and in identifying teaching approaches in labwork at these levels. Evidence was presented that large numbers of students in the sample drew upon images of science when answering the Probes that are potentially unhelpful during labwork learning. The following recommendations are therefore made about curricula and teaching approaches as they affect student learning through labwork in the upper secondary and university curriculum:

1 Many students are likely not to recognise the epistemological basis of routine algorithmic procedures used for data handling during labwork, such as estimating values from sets of data and drawing lines and curves through measured data points. In some cases, this is likely to lead to students taking inappropriate actions during their labwork learning (such as assuming that computers can solve problems of data analysis, not recognising the need for scientists to instruct computers how to handle data according to specific requirements). Findings from this study suggest that individual students draw from a range of images of science in acting in various situations. For many students, it may therefore be necessary to introduce ideas about the epistemological basis of routine algorithms for data analysis, as well as to give

students experience and practice at applying this reasoning in a variety of appropriate labwork contexts.

We therefore recommend that explicit teaching is planned in the curriculum to teach students about the epistemological basis of data analysis in contexts close to those likely to be encountered during routine labwork.

We further recommend that the epistemological basis of data handling is made explicit, rather than treated as understood, during labwork teaching activities involving the use of such algorithmic procedures.

2 Many students are likely to see knowledge claims as emerging directly from the logical analysis of data, not recognising how particular theories and models help to shape scientists' ways of evaluating and interpreting data. This may lead to inappropriate behaviour during labwork, such as students not recognising how theory might be drawn upon during experimental design, analysis and interpretation. Findings from this study suggest that many students are likely to focus upon data alone, and that some students will adopt a radical relativist position, assuming that there is no rational basis for evaluating knowledge claims during empirical work.

We therefore recommend that, through the science curriculum, students are exposed to philosophical ideas about relationships between knowledge claims and data. These ideas should be presented to students in contexts close to those likely to be encountered during other aspects of their studies in science.

We further recommend that students' attention be drawn explicitly to the role of theory in the design, interpretation and analysis of data during a range of labwork activities.

3 Some students appear likely to draw strong conclusions from empirical investigations, based on inconclusive evidence.

We therefore recommend that, through the science curriculum, students are exposed to examples of empirical investigations and issues related to drawing conclusions from those investigations. Examples might include case studies from the work of professional scientists, or students' own labwork.

3 . 2 . Pilot study 'teachers' image of science'

Milena Bandiera, Francisco Dupré, Carlo Tarsitani, Eugenio Torracca, Matilde Vicentini,

Marie-Geneviève Séré

3 . 2 . 1. Introduction: why focus the inquiry at the teacher level

Research in Science Education has shown the relevance of the image of science both as an *object* of teaching and as a source of underlying assumptions in the teaching activity and in the research itself. However, the present status of the research on the images of science has not yet reached a full clarity in the presuppositions. We don't have clear cut answers to fundamental questions such as:
- is the student's image of science relevant for her/his science *learning*, and why?
- is the teacher's image of science relevant for her/his science *teaching*, and why?

In any case, every critical discussion on this problem should start form the fact that knowing "science" and knowing "what is science" are at two different cognitive levels. Knowing "science" implies the understanding of the contents agreed upon by the scientific community on the basis of the observation and experimentation on natural phenomena and of the theoretical framework which gives account of the empirical data.
Knowing "what is science" implies a meta-reflection on the production and evolution of those contents, that is on the procedural methodology of making observations, planning experiments, developing theories and models, comparing theoretical analysis with empirical data. It may also imply some knowledge of the social aspects of making science (science policy, institutional organisation, research groups interactions, publication procedures, scope of conferences and symposia, the exercise of debate, etc.) and of the role of scientific research in society at large.

One may observe that the problem of the relation between theory and experimental data appears at both levels of "knowing science" and "knowing about science" . While it seems possible to learn science without knowing what is science, the reverse is not true: meta-reflection is possible only if there is some knowledge on which to act at the meta-level. Of course it may be possible to plan a didactical interplay between the communication of contents and the meta-reflection on science but this is not usually done in secondary schools and in university teaching. Moreover it would require a special training of the teachers which is not present in standard teachers education and training courses (which will be set up in Italy only from the next year).
An implicit image of science is conveyed to students from the didactical presentation given in classrooms and textbooks. In Italy, (and in many other countries) it is this "school" image of science that is eventually transmitted to the students. At the same time, students - and teachers too - are exposed to other sources of implicit/explicit information about the nature of science like mass-media. Therefore the ideas that students develop about the nature of science will be strongly related to their teachers' ideas, both for scholastic and for extrascholastic reasons. Therefore, a research on students image of science must be completed by a parallel research on teachers image of science. An implicit image of science is also conveyed by the ordinary school labwork courses. The idea that only the school labwork activity may help students to understand the nature of scientific

investigation is widely diffused. However reasonably it cannot be claimed that practicals reflect real scientific labwork research. So, if we think that labwork offers a special opportunity to let students understand something of the nature of scientific research, any project on the role of laboratory at the secondary school level and at the university level should be based on an image of science which takes into account the complexity of the relationship between theories, models, experiments, technology in actual scientific research (see next section).
At the same time, the Italian group, in charge of this survey, is strongly convinced that this complexity is not available to students unless explicitly communicated. Therefore students cannot develop at an early age any image of science strictly speaking, which includes the above aspects. So our choice would be to restrict any survey about students' image of science, to the end of secondary school and university courses.

We are convinced that the development of a reasonable image of science must be an objective of science teaching. Of the different arguments which may be invoked, we will privilege a "cultural" argumentation (to understand science should be integral part of a "modern" education for the average citizen) and a "democratic" one (to be able to understand the scientific results as proposed by the mass-media and eventually participate with some competence in political decisions that involve scientific aspects.)
In this perspective, we claim that the particular "rules" of labwork should be "understood" as a result of the general progress of science, that is also in their "cultural" value. We also claim that any survey on the images of labwork should care for a precise use of the terms theory, model, empirical data, etc., avoiding any common sense ambiguity.

So, we come to a crucial question: in what sense should we teach a "correct" image of science?
There is a lively debate about what may possibly be a "correct" image of science. Such a debate involves philosophers, science educators and scientists. However, while philosophers and science educators are exchanging ideas in conferences (see the periodic meetings of the "History, Philosophy and Science Teaching" international group: Tallahassee, Kingston, Minneapolis) and in the educational literature, scientists are more often discussing within their community, which is in general reluctant for discussing with philosophers, and very rarely engaged in the connected educational problems. The communication gap between scientists and researchers in education is quite symmetrical as the last seem to prefer to listen to what philosophers say about the work of a scientist than to scientists speaking of what they are actually doing.

In any case, we are convinced that, in order to facilitate communication, researchers in science education should make explicit the image of science that guides their work. In section 3.2.2 we will expose the aspects of the image of science that the Italian group recognises and that have been discussed with the other groups . Section 3.2.3 reports on the criteria of the choice of the questions for the pilot study whose results are given in section 3.2.4.
In order to place the research in the educational context of the training of the teachers, we made a description of the Italian and French situations concerning teachers'training. We also took into account the researches that have appeared in the literature in the last years, seldom addressing the ideas teachers have about experimental work performed either in research activity or in school practicals. Both studies can be found in the corresponding Working paper.

3 . 2 . 2 What is science?

A lively discussion took place in the group in order to reach a shared agreement on some features of an answer to the question in the title. The opportunities of discussion were not only this survey, but many others. Everyone brought ideas taken from the literature on the subject by scientists and philosophers and from their personal experience as scientists or historians of science. In the following, we will state what we agreed upon for the three aspects: a) aims of scientific work, b) structure of scientific knowledge, c) science as a social enterprise.

a) The aims of scientific work

Notwithstanding the fact that knowledge of natural world is a product of the human cognitive ability which has roots in the prehistory of mankind, being an ability of essential importance for surviving, we continue to ask ourselves what are the aims of the kind of work we call nowadays “science”. If we look at the history of modern western science, we see that, since the beginning of the so called “scientific revolution” scientists themselves were engaged in a lively debate on the aims and the scope of the new “Philosophy of Nature” (think, for instance, about the debate between cartesians, leibnizians and newtonians). The “modern” epistemological debate arose probably from the well-known “crisis” of the mechanical world picture at the end of the last century (Duhem, for instance wrote his famous book to show that the aim of physics is not to “explain” but to “describe” and “classify” phenomena). In present times, the military applications and the environmental issues seem apparently to suggest that scientific activity still requires a justification in front of society.

We may look at a definition of the aims of science from the inside of the scientific community and from the outside. Epistemologists look at science from outside, doing research on problems which have become part of the traditional problems of their community and which are not shared by professional scientists. On the other side, professional scientists are part of a “scientific community” with specific rules of social organisation of scientific work. We should then take into account not only the aims but also the rules of the game of the scientific community.
Every member of this community will easily agree that the aims of his work are:
i) to increase the understanding of the world we live in,
ii) to develop knowledge aimed at a better control and prediction of phenomena and events,
iii) to make this knowledge “useful” in the development of new technologies.

To reach these aims the scientific community puts as a rule of the game the confrontation of ideas, theories, experimental outcomes among different scientists, research teams, etc. Anyway, since “originality” is a prerequisite for good research, each individual contribution, which obviously may incorporate opinions, styles, tenets of individual scientists, restricted groups, etc., is subject to the scrutiny of a wider scientific community (for instance of the “referees” of scientific reviews) which in turn is subjected to more general rules. Here may be found a difference between theoretical and experimental research, being the last more aimed at the reaching of an intersubjective agreement based on the reliability of data.

Instruments for the confrontation are scientific reviews, conferences and symposia, scientific societies, workshops, etc. Therefore the terms of the confrontation are, on one side, the natural world of phenomena (which includes the experimental outcomes of laboratory practice) and on the other, the different points of view of different scientists and the exercise of accurate criticism. Thus, the development of science requires both an “intersubjective” agreement on rules, criteria, models of explanation, background knowledge, etc., and the competition of different point of view, via scientific debates and criticism.

b) The structure of scientific knowledge

Today science is organised in different fields, each characterised by a common shared set of theories, models, empirical laws, methodologies of research. This common shared knowledge is, as we have already pointed out, the knowledge obtained on the part of the world pertaining to the field of research by the intersubjective agreement among different scientists who have the competence for comparing models and theories with natural phenomena, experimental outcomes, technological products.
Therefore each subfield has its own specificity and scientists of the different fields may have difficulty in communication. However the relationship between theories/models/experimental outcomes/technological products crosses over the different fields of the experimental sciences.

The relation between the *‘real world’* of facts/events/phenomena and the *‘ideal world”* of models and theories may be roughly described as a relation of *‘mapping’* or *‘modelling’*. Scientific theories construct an ideal world that may be used as *a ‘model’* for finding ways of describing or explaining phenomena, processes, objects, etc. of the “real world” and the “empirical laws” obtained by correlating parameters and measured quantities. The empirical laws may ‘explain’ a phenomenon by including it into a wider class of ‘similar’ phenomena. So the statement 'data are theory laden' should be changed in 'any research project, either theoretical or experimental, is, at a given time, laden by all the shared knowledge in the three aspects of theories/models, experimental outcomes, technological artifacts'.

The problems on which research may develop are of different types:

a) development of theoretical aspects related to new or anomalous data,
b) logical organisation of theoretical aspects,
c) technological development,
d) experimental verification/falsification of theoretical hypothesis,
e) experimental exploration of fields opened by theoretical or technological developments,
f) analysis of experimental data in search of empirical correlation/generalisations,
g) analysis of experimental data in the light of new theoretical hypothesis.
h) collection of observational information and correlation.

c) Science as a social entreprise

The scientific community judges the validity of a research project (theoretical or experimental) and of the research by the confrontation of the different points of view of scientists and of the theories with the experimental outcomes. The confrontation aims at an intersubjective agreement devoid of personal biases or belief systems but these cannot be completely avoided. They may be particularly relevant when experts have to make decisions on the financial support of research projects.
Experimental work is nowadays organised as a work group in which every scientist contributes according to his/her particular competences and capacities. Requesting a large financial support, any research project is always conditioned by its socio-economic-

political context.

3 . 2 . 3. Criteria for the choice of questions and samples

The choice for the questions done by the Italian group was guided by the group's image of science and framed by two constraints: the involvement in the LSE project and then the Italian context.
Though we agree - and have experimented - that it is more appropriate (in investigating about the image of science) to use concrete examples and not general questions , the second constraint forced the Italian group to change or abolish the context, when the subject of the question selected from the data base was placed in a context which could be inappropriate (and therefore questionable) to the Italian teachers.

The final set of questions is given in the Working Paper 5
Questions 5 and 8 were also used in a questionnaire submitted to a French sample of teachers (see Appendix of the Working Paper 5)

In Italy the respondents were biologists (7 university and 8 secondary school teachers), chemists (11 secondary school teachers), physicists (5 university and 8 secondary school teachers).
In France the sample amounted to 106 teachers: biology and geology (12 university and 30 secondary school), physics and chemistry (33 university and 31 secondary school).

3 . 2 . 4 Questions and results

The questions will be evaluated by alternating the mental representation shared by most of the questionnaire respondents (a), with the description and the critical analysis of the question itself (b); possible modifications are then discussed. Both aspects will be discussed on the basis of the Italian sample. For questions 5 and 8 this discussion will end with a comparison with the French sample.

Three questions have been eliminated after piloting. They respectively concerned the identification of causes of error in experiment, experimental procedures in a biology context and generalities concerning the nature of science. The questions themselves and the corresponding critics can be found in the Working paper 5.

Question 1 [type : General question about science]

The teachers were given general statements concerning the aim of scientific activity, to agree/disagree with.

a) Scientific activity is aimed mainly at giving 'a rational explanation of the phenomena of nature' (84%) and at 'discovering the fundamental laws and entities of the world we live in' (83%); secondly at 'enhancing the capability to predict and control natural phenomena' (78%) and at 'solving practical problems in order to improve living conditions' (71%). The cognitive side seems to prevail over the applicative one.
b) This general question on the aims of scientific activity is a reformulation of a question previously proposed by the German group. In our intention the cognitive function of science is represented by conflicting conceptions/items: the discovery of immanent laws, the formulation of rational explanations, and the achievement of an intersubjective agreement in the scientific community. The practical-applicative function is represented by the solution of practical problems, by the enhancement of the capability to predict

and control natural phenomena and to modify the environment.

From the answers it is clear that conflict between the discovery of immanent laws and the intersubjective agreement is hardly perceived.

The question is judged **valid with slight modifications**.

Question 3 [type : General question about experiments in science]

General statements were proposed to teachers concerning four theoretical claims, in physics, chemistry and biology

a) The assertions destined to be integrated into scientific knowledge are founded essentially on the progressive accumulation of theoretical knowledge (79%), and of experimental data (84%), characterised by objectivity (90% of the inteviewed excluded the relevance of intersubjective agreement).

b) It is a general question about the role of experiments in disciplinary contexts .

The four initial assertions concern various sectors of experimental sciences: the degree of familiarity with the single sector could impact significantly on the evaluation of the importance of the items. The items present alternatives between experimental data (A and D) and speculation (C, E and B) and between objectivity (A, D) and subjectivity (F) of knowledge.
The data seem to reveal a propensity on the part of university teachers, physicists in particular, to underestimate the importance of theoretical (reasoning, deductions) and mathematical elaboration.

The question may be considered **valid**.

Question 4 [type : General question about experiments in science]

a) The research set up according to a method that can be defined scientific is founded on sound observations and experiments that are repeatable (89%), performed under analytically identified and perfectly controlled experimental conditions (82%), and repeated an adequate number of times (72%).

b) This question has been used by Milena Bandiera in a previous research and it has already shown his efficacy in stimulating clarifying discussion in the classrooms.

The statements belong to two categories:
i. 2 statements focus, directly, on the basis of the relation between knowledge, experimental data and theory,
ii. the others consist of extreme or hypergeneralised definitions of the elements used canonically in presenting the 'scientific method'.
It is possible, on the basis of the previous administrations followed by a considerable number of interviews, to guarantee the efficiency of the set of statements with respect to the possibility of focusing on and comparing, within a didactic scope, divergent positions.

With respect to the data already available (which derive from first-year students enrolled in the Degree Courses in Biological Sciences), the administration of the questionnaire to the teacher sample confirms the uncertainty of the concepts of 'theory' and 'model' , the weight of the resonance of widely employed formulas for definition, and the possibility of perceiving the ambiguous features of apparently shareable statements.

The question can be considered **valid**.

Question 5 [type : on data interpretation]

The teachers had to decide if there is a unique or not interpretation of given data
a) For Italian university teachers, experimental results can be interpreted in different ways (73%) and scientists are guided by theoretical assumptions (83%). For secondary school teachers the two alternatives are shared with respectively 75% and 56% percentages.
b) The question, from a proposal of the German group, concerns the interpretation of experimental data: their intrinsic 'objective' meaning and the weight of theory on the interpretation procedure.
Without underestimating the differences between university and secondary school teachers, the main interest of the question concerns the reasons the respondents give for choices between the alternative answers. These reasons concerns the theory / data relationship, where the word 'theory' is intended also in terms of hypothesis or a priori knowledge.

In France the questions has been proposed with a slightly different wording ‘analysing’ instead of ‘interpreting’ and the sentence : “good scientists must ...”. The number of teachers who do not accept both the proposed answers is high. For those who choose, the results are similar to the Italian sample.

The question appears to be **valid in the main**. However a subsequent discussion of the question with a group of student teachers has shown that the use of words like “always” and “never” and ‘must’ should be avoided.

Question 6 [type : question about scientific procedures]

The question has been posed in several countries to students (see section 3.15). It concerns the decisions to be taken following contradictory experimental results.
a) The scientific validity of a statement is corroborated by empirical investigation (100%) on the condition that they involve the experts (80%) and that they are not founded on opinions (86%).
b) The alternatives have a scientific (A, C) or pseudoscientific (D) basis, privilege reference to scientific knowledge (E) or of common-sense (even if expressed by persons 'involved') opinions (B, D).

Alternatives A, B and D appear relevant and significant. The evaluation of C possibly reveals the spread of 'animalistic' positions: indeed, although alternative C comprises an empirical investigation like A, unlike A it has evaluations characterised by a notable spread: it is sustained predominantly by university teachers (60%) and biologists (60%). The function of theoretical elaboration appears to be controversial (sustained principally by chemists).

The question appears to be **valid.**

Question 8 [type : data interpretation]

The questions, open-ended, concerned two different graphs drawn by two researchers from the same data

a) We grouped the answers in the following 4 categories (in order of decreasing frequency):
   1. the various interpretations depend on the reference to various theories or prejudices of the scientists (11);
   2. the various interpretations depend on the data analysis methodologies used (8);
   3. in any case the straight line is preferable, 'objective' (6);
   4. both the quality of the data and the correlation between data and interpretations are modest (2).

The same categories and ranking apply to the part of the question related to the discussion among researchers.

b) This question concerns data interpretation (from an idea suggested by the French group DIDASCO), with special attention to the strategies for interpretation and the role of computer.

As regards the role of computer, more than 50% of teachers answer “yes”.
In France the results are comparable, but category 2 has been split in two (help gained from a computer, ability of the computer to choose) For the majority a computer is not able to make such a decision.

Data are coherent and comments are relevant and evocative: **a good question**.

Question 10 [type : question about general experiments in science]

The question was about differences between experimental activity at school and in a research laboratory

a) The two types of experimental activity are distinguished especially in the view of university teachers, in terms of the features of the experimental apparatus: how sophisticated it is (79%), how careful the planning, the verification, the improvement (70%). To those who express their position in this regard, the activity in a research lab appears to be characterised by the fact that the results are not known before and are subject to the validation of 'peers' (81%).
b) The comparison between experimental activity in a research lab and in a school lab is presented.

The experimental activity in the items is represented by objectives, execution modalities, resources, work typology and operators and referents.

The question appears to be **valid**.

3 . 2 . 5. Conclusions

The first aim of the pilot study was to validate a set of questions selected by the pool of question formerly proposed by the European group. Most of the questions (1, 3, 4 and 10:

general questions about experiments, 5 and 8 : *data interpretation*, 6 : *scientific procedures*) may be considered valid with sometimes slight modifications.
Question 2 about scientificity should be modified or suppressed, as having similar intentions as others (1 and 3).

From the answers to the valid questions we can infer some hints about the Italian teachers' image of science.
A. Scientific activity is aimed at giving an explanation of the phenomena of nature by discovering its objective, fundamental laws.
B. Scientific knowledge evolves by progressive accumulation of theories and experiments.
C. Scientific research is founded on a method which requires sound observations, repeatable and perfectly controllable experiments.
D. In the interpretation of experiments scientists are guided by theoretical assumptions.
E. Empirical investigation is needed to assert the scientific validity of any statement.
F. Conflicting interpretation of data may be due to theoretical commitments (most of the University teachers) or to problems of data analysis (most of school teachers).
G. School laboratory differs from research laboratory, mainly because of the equipment used.

The opinions of school teachers and those of university teachers are not so different. The only relevant differences may be found in their shaping the distinction between research laboratory and school laboratory (question 10) and in the role of theoretical commitments in data interpretation (question 5).
The interviewed university teachers - all experimental researchers - appear to be stimulated by a question only when it regards the specificity of experimental work; the other generic questions seem to stimulate answers related to their teaching practice, while the answers to general questions about science show a "conformist" attitude towards a "common place" image of science.

Chapter 4

TEACHERS' OBJECTIVES FOR LABWORK.

Manuela Welzel, Kerstin Haller, Hans Niedderer and Stefan von Aufschnaiter

The aim of this survey is to study teachers' objectives for labwork at both academic levels under study, for all the countries members of the project.

4 . 1 Research Questions

The realisation of this survey was planned in the proposal itself : 'Given the fact that in effectiveness, the role of teachers is predominant, it appears necessary to study the distance between the main goals recognised by teaching staff, and the main goals they really carry out.' We wanted to know more about the real situation on what have teachers in mind, when organising labwork. Are there any subject-, level- or country specific objectives followed when organising labwork?

4. 2 Methodology

4.2.1 Introduction

We did not want to give a priori defined categories of objectives to the teachers. We wanted to get spectrum of statements (objectives) which is as wide as possible. Moreover one potency of this project is its internationality. Because of cultural and linguistic differences between the participants we could not assume a common understanding of items pre-formulated by a German group.

Thus, we had to find and practise a technique appropriate to the assumptions. One appropriate technique is the Delphy method

4.2.2 The Delphy-Method

The Delphy method is an iterative procedure for questioning large groups of persons. It grounds usually in the following three elements:

Element 1. One group of persons will be questioned individually and anonymously.

Element 2. The questioning will be repeated within 2 to 4 circles.

Element 3. The repetition will be organised on the basis of the interpretation of the precedent rounds.

The study was organised in three steps according to the Delphy method:

(1) we 'piloted' teachers' objectives using three open questions

(2) we abstracted out of these data categories of objectives and compared these categories with those published in the literature

(3) with a multiple choice questionnaire we let teachers rank and judge the piloted categories of objectives according to their importance and the usefulness of different types of labwork

- The three open questions, were intended to get *empirical* results about possible objectives for labwork in general and according to special types of labwork, and characteristics for 'good' labwork
- The questions were at first formulated by the German group in English language. The final questionnaires were distributed to 10 teachers of each country covering all levels and subjects. After answering the questions the statements of the teachers were translated into English language and sent to Germany.
- Out of the teachers' statements, we abstracted 5 main categories and 33 sub-categories of objectives. These categories of objectives were compared to objectives formulated in the literature.
- A detailed multiple choice questionnaire was designed on the basis of the first step of investigation. With this second questionnaire 10 teachers of each country, level and subject (altogether around 409 teachers)

(1) had to rank five main categories formulated on the basis of the empirical data out of the first step,
(2) had to judge 33 sub-categories of objectives according to their importance with respect to labwork, and
(3) had to judge five different kinds of labwork according to their usefulness to reach the different main categories.

We gave in all categories a free line to the teachers to have the possibility of filling in missed categories of objectives.

4.3 Data analysis - 1

Data analysis—open questions and abstraction of categories of objectives

As expected we got a wide spectrum of objectives formulated by the 60 teachers (each country, level and subject), altogether 317 statements from which we could abstract categories. In a further step, in our research group we tested the inter-subjectivity of the assignment to the categories. An accordance of around 90% was reached.

The following *main categories* of objectives and *sub-categories* of objectives for labwork emerged :

Objectives for labwork are

(A) for the student to link theory to practice,

(B) for the student to learn experimental skills,

(C) for the student to get to know the methods of scientific thinking,

(D) for the student to foster motivation, personal development, social competence[1] and

(E) for the teacher to evaluate the knowledge of the students.

For A there are 12, for B 6, for C 8, for D again 6 subcategories.

[1] This category contains three very different aspects - motivation, personal development and social competence. However, we put them into one category because they all represent a social dimension. Dividing this category into three single items could overestimate the social aspect within the whole set of categories.

A for the student to link theory and practice

A1	to facilitate the understanding of the theory
A2	to verify scientific laws
A3	to produce (certain) phenomena
A4	to make the understanding of theory better through practice
A5	to illustrate phenomena for the students
A6	to make explicit specific experimental methods for specific topics (content)
A7	to observe and experiment for future use in theory development
A8	to deepen by example a subject systematic approach
A9	to introduce notation and technical terms
A10	to solve problems which arise from an experiment
A11	to demonstrate technical applications
A12	to help remember facts and principles

B for the student to learn experimental skills

B1	to get experience in standard techniques and procedures
B2	to learn a method using an example
B3	to learn and to practice how to write a lab report
B4	to learn how to make careful observations
B5	to learn working in a proper and safe way
B6	to handle with experimental errors

C for the student to get to know the methods of scientific thinking

C1	get to know the scientific approach
C2	to learn scientific thinking
C3	to develop skills of planning and experimenting in general in sciences
C4	to develop a critical approach to interpreting data
C5	to learn and to handle science as complex networks
C6	get to know epistemological methods
C7	get to know how scientists work professionally
C8	learn to deal with equipment difficulties in general

D for the student to foster motivation, personal development, social competency

D1	to develop interest
D2	to enjoy subject and activity
D3	to develop general skills of communication and interaction
D4	for the teacher to give and for the student to get motivation
D5	to learn how to work in teams
D6	to develop awareness of natural environment, responsibility, tolerance (ethics in science)

For the purpose of investigating which types of labwork seem useful to reach these objectives, we used the '*map ofvarity of labwork'* elaborated through the project. Finally, we decided to take the following five types of labwork:

- demonstration experiments
- experiments carried out by the students
- open ended labwork
- strongly guided experiments
- using modern technologies

4 . 4. Data analysis - 2

In the third part of our study, using the presented questionnaire, we asked 60 teachers of each participating country to rank the main categories, to judge the importance of the defined sub-categories for labwork in general and in relationship to the type of labwork.

Level-Country-Sample:

Count

		level		
		Secondary school	University	Total
country	Denmark	32	27	59
	France	76	52	128
	Germany	37	35	72
	Great Britain	23	24	47
	Greece	30	30	60
	Italy	28	15	43
Total		226	183	409

Subject-Country-Sample[2]:

Count

		subject			
		biology	chemistry	physics	Total
country	Denmark	20	15	22	57
	France	50	48	29	127
	Germany	19	21	32	72
	Great Britain	16	12	16	44
	Greece	16	16	28	60
	Italy	13	11	19	43
Total		134	123	146	403

All these data were analysed quantitatively using SPSS.

4 . 5 Results

Because of the limited samples in each country, subject and level, we decided to be careful with the formulations of 'results' with respect to objectives followed by teachers when organising labwork. We exclusively can show tendencies found in the data set, or formulate hypotheses to go further in the research within this field, or ask questions. Nevertheless, we now are able to present interesting tendencies.

4 . 5 . 1 Main Objectives for Labwork

As said before, the teachers had to answer the following task:

Please rank the objectives in the order of <u>1 - highest rank</u>- to <u>5 - lowest rank</u> using each number only once.

	Objectives for labwork are	**rank**
A	for the student to link theory to practice	
B	for the student to learn experimental skills	
C	for the student get to know the methods of scientific thinking	
D	for the student to foster motivation, personal development, social competency	
E	for the teacher to evaluate the knowledge of the students	

Looking at the frequencies of the ranking of each single category we got the following results (n_{total}=409):

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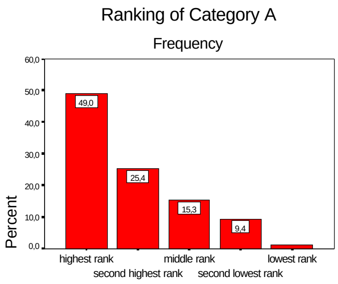
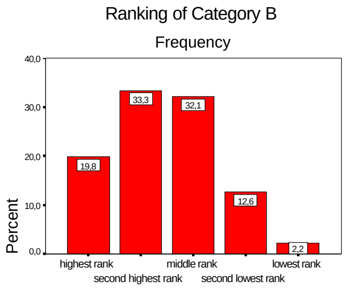
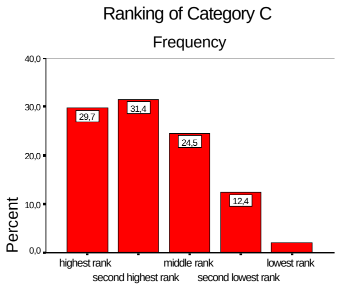
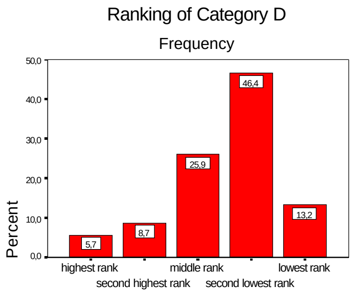
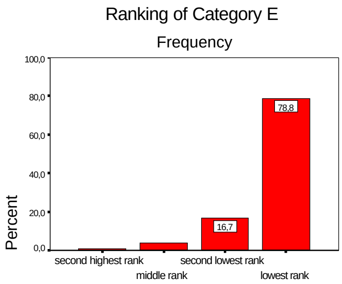
[2] Six teachers did not give the information about the subject in the questionnaire. Thus, we have 6 answers less for the subject-country-sample.







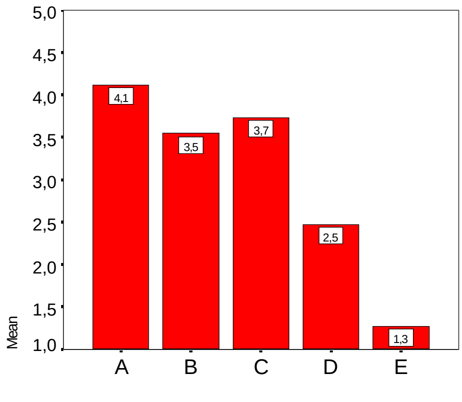




More than 40% of the teachers ranked the category A (to link theory to practice) as the most important one. The categories B and C got both the most weight for the second rank, but C (for the student get to know the methods of scientific thinking) got more often than B the highest rank. Category D (to foster motivation, personal development, social competency) is mainly ranked lower than the first three categories, but there are 14% of the teachers who put it at the first or second position.

Calculating the mean value of the rank of all categories across all countries and country sample specific we get the following results[3]:

Mean value of main categories (all countries)



mean-value main-categories - statistics

	N		Mean	Mode	Variance
	Valid	Missing			
A: link theo. and prac.	406	3	4,12	5,00	1,09
B:exp. skills	405	4	3,55	4,00	1,03
C: scien.think	404	5	3,74	4,00	1,17
D: motivation	401	8	2,47	2,00	1,03
E: eva. knowledge	401	8	1,27	1,00	,35

The data show a rather coherent rank of the main categories A, B and C.

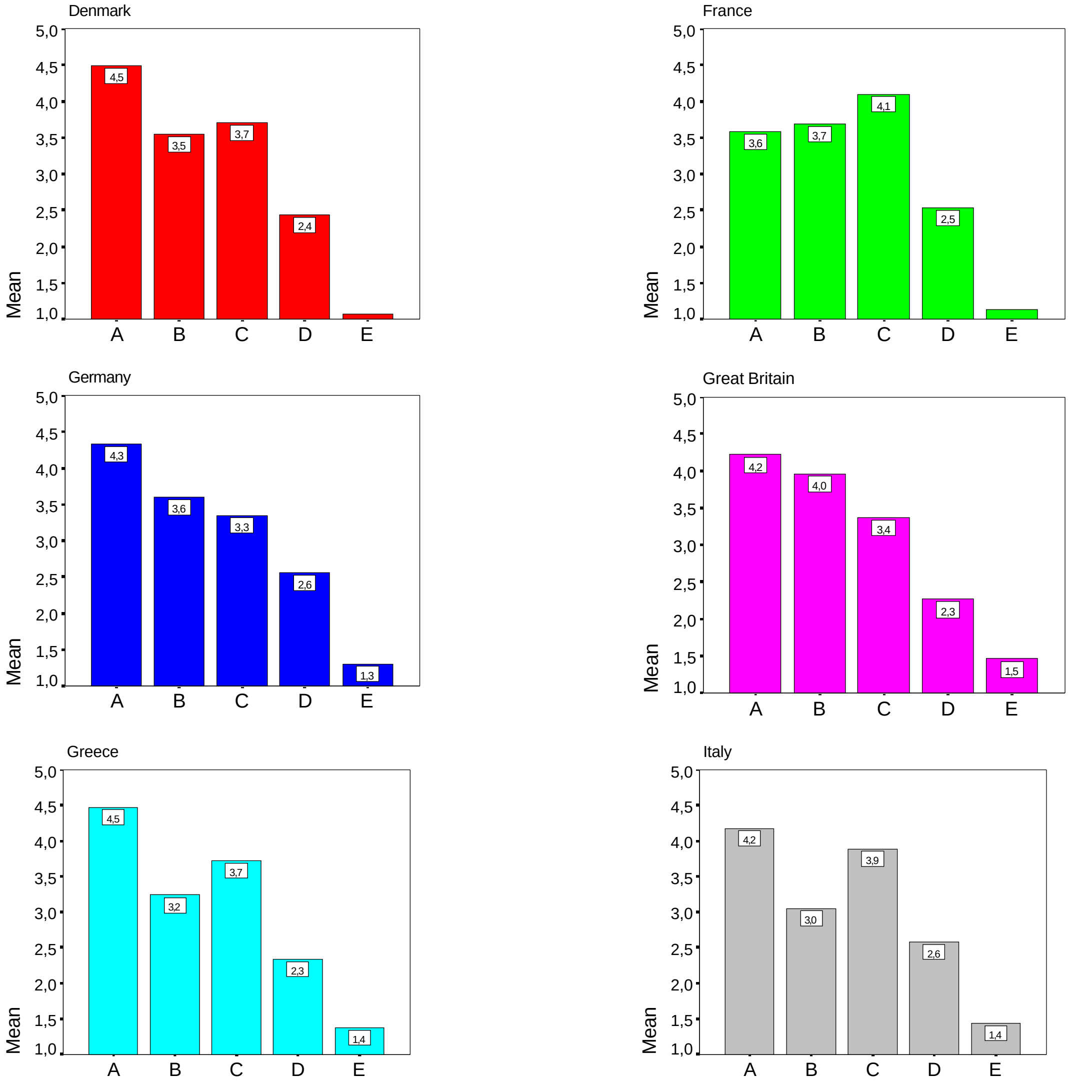
[3] Every time we will speak about similarities or differences we will have checked the significance of the predication by mathematical means.

! **(A) to link theory and practice, (B) to develop scientific thinking, and (C) to develop experimental skills, were ranked as the main important categories of objectives for labwork.**

The differences between the country samples[4], between the level specific and subject specific answers are rather small (see next graphs and tables). But there are some interesting phenomena:

COUNTRY SAMPLE SPECIFICS

Mean Value of Main Categories for each Country



The French sample as the only one shows the highest value of 'to develop scientific thinking' - whatever it is meant by this - through labwork.

LEVEL SPECIFICS

There are some significant differences between the answers of the different levels:

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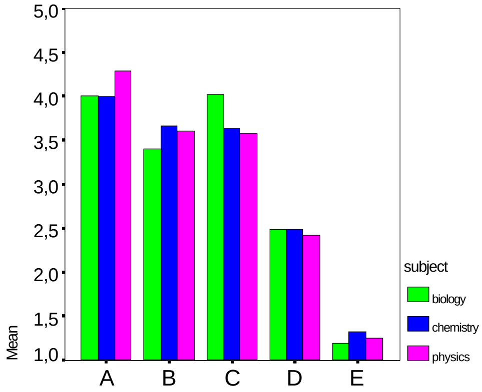
[4] We use the term 'country samples' because the data set is limited according to its number. In addition, the questionnaires were differently distributed in the different countries, thus representativity with respect to a country is not given.

! The objective **'to learn experimental skills'** seems to be **more** important for labwork at university than for labwork at secondary school. The same tendency we can find in the data on the sub-categories.

! **'To foster motivation, personal development and social competence'** by doing labwork were ranked **higher at school level** than at university level. The same tendency we can find in the data on the sub-categories.

SUBJECT SPECIFICS

The answers of biology and physics teachers show two specific features:



! The category C ('**to get to know the methods of scientific thinking**') is **ranked higher by the Biology teachers** than by the others and, it is higher ranked by them as 'to develop experimental skills'. This effect becomes evident throughout the whole data set[5].

! '**To link theory to practice**' through labwork is ranked **highest by physics teachers**.

The second result seems to reflect one central problem of physics teaching: Investigations of conceptual change and misconceptions did show in great detail the difficulties of students to use individual experiences for the explanation of physical phenomena and for mathematical modelling or description of physics phenomena. Experiments are mainly done to overcome these problems.

4 . 5 . 2 Sub-categories of Objectives for Labwork

In the second part of the questionnaire, the teachers had to judge the importance of all sub-categories of objectives.

Especially the sub-categories of B (to learn experimental skills) and of D (to foster motivation, personal development, social competency) were judged coherently as very important by all. Within category B item B4: 'to learn to make careful observations' gets the highest marks. In D there are items like: 'to develop interest through labwork', or 'to enjoy subject and activity', or 'to develop general skills of interaction and communication'.

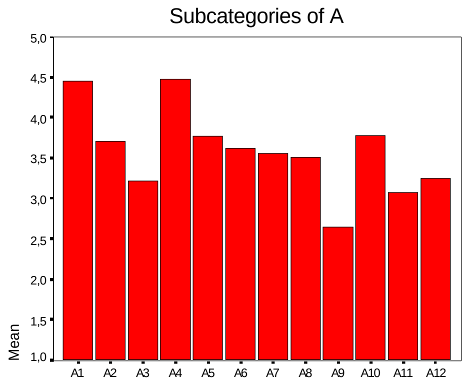
[5] Looking at the mean value of the main categories it seems to be an effect produced by the French sample answers. Checking this according to the other samples and the levels, we must say that category C is higher ranked by all Biology teachers.

For E we only had one category which was judged now high for its importance , and in addition it was intensively discussed by the teachers. There we could see the problem of how to assess or evaluate students' knowledge during labwork. The teachers normally have to evaluate, but they do not really know how to do this in a fair and reasonable way.

The sub-categories of A 'to link theory to practice' and C 'to learn the methods of scientific thinking' generally were judged differently and inhomogeneously with respect to their importance. This result and the discussions within the international research group let us think about different understandings of single items or misunderstandings according to the use of language.

This phenomenon we now want to analyse in more detail. With the following tables and graphs we want to drive the attention on the distribution of valuation. We will begin with the sub-categories of A and C - because in both we found inhomogeneousness - , and than, describe the results for D and E.

The sub-categories of A - to link theory to practice



The data show a relatively incoherent profile. There are sub-categories which are seen as very important objectives and some are seen as less important:

important	less important
A4 understanding of theory through practice	A9 - introduce notation and technical terms
A1 improve understanding of theory	A3 - make phenomena occur
A10 solve problems which arise from an experiment	

This result could reflect differences between the teachers according to the importance of single objectives, or cultural and lingual differences and problems of understanding the items. Deeper analyses show, according to the ranking in the first part of the questionnaire, the common view of the teachers asked that the main objective within A is to develop and improve the understanding of theory through practice (A4 and A1). The experiment has to be understood as a tool to learn theoretical descriptions of theory. The weight is on theory. An other argument is that only a small percentage of missing values in these categories occur.

Country sample specifics, subject specifics and level specifics:

FOR A

- There are very **high values** (higher than 4.2) for A2 (to verify scientific laws) and A8 (to improve a systematic approach) given by **Greek teachers**.
- There are very **low values** (lower than 2.5) given by **Danish teachers** for A6 (make specific experimental methods explicit) and given by **German teachers** for A9 (to introduce notation...).
- There are **no subject specifics** for the answers in category A.
- Only for A3 (to make phenomena occur) and A10 (to solve problems which arise from an experiment) the **university teachers give higher values** to the sub-categories of A than the school level teachers.

We propose to change the description of the item A3 into 'to demonstrate specific physics phenomena (like friction, buoyancy etc.)'

FOR C

- The **Italian teachers** judge **all items higher** than the others.
- C6 (to get to know epistemological methods), C7 (to get to know how scientists work) and C8 (learn to deal with equipment difficulties) are judged **significantly lower** by the **teachers of France and Great Britain** than by the others.
- For C1 (get to know the scientific approach), C2 (to learn how to think scientifically), C5 (learn and handle science as complex networks) and C6 (to get to know epistemological methods) the **Biology teachers** give the highest values.
- All categories are judged higher by the **university teachers**.

Because of misunderstandings with this item we propose to add to the description of item C6 'e.g. inductive, deductive'.

FOR B and D

- There are no country sample specifics.
- Chemistry teachers give in B the highest values for all items.
- The sub-categories of D are judged in the same way (very high) by the teachers of all the three subjects.
- University teachers judge the importance of experimental skills to learn higher than school teachers.
- Secondary school teachers give higher importance to the objectives of D than university teachers. They feel more responsible for the development of students' social competencies.

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4 . 5 . 3 Types of Labwork and their Usefulness to Reach the Objectives

Types of Labwork

In the third part of the questionnaire the teachers were asked to judge the usefulness of different given types of labwork — 1 demonstration experiments, 2 experiments carried out by the students, 3 open ended labwork, 4 (strongly) guided labwork, 5 experiments using modern technologies — for reaching the main objectives[6]. (It could be ticked the items 'very useful', 'useful', 'can't decide', 'less useful', 'not useful'.)

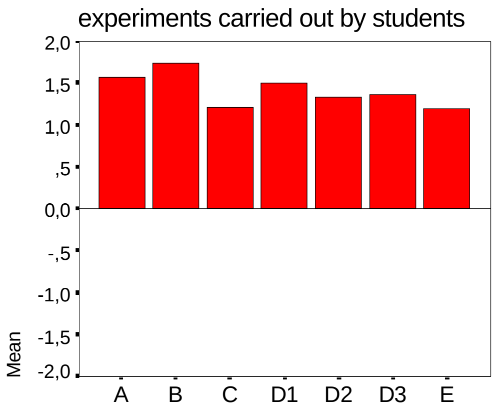
For the usefulness of the different types of labwork for reaching *all main objectives in general* we got the following rank:

1. experiments carried out by the students
2. open ended labwork
3. using modern technologies
4. strongly guided experiments
5. demonstration experiments

In general the 'normal' labwork practice, usually organised (experiments carried out by the students) were judged as very useful to reach the named objectives. Demonstration experiments were seen as less useful to reach the given main objectives. See the following graphs:

Rank of different Labwork Situations

1



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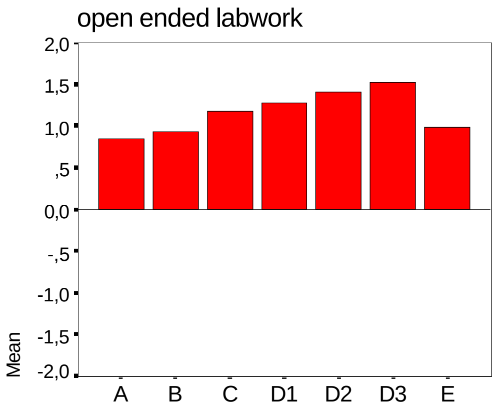

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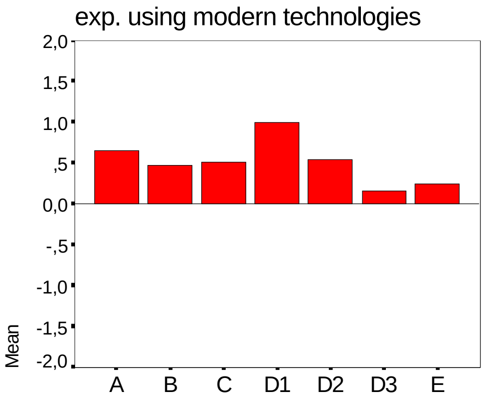

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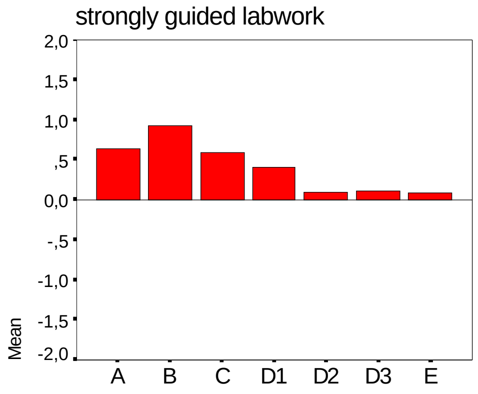
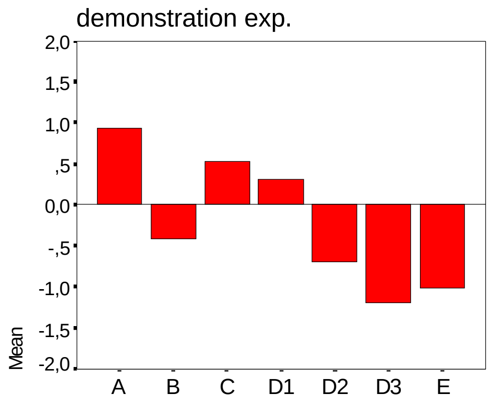


[6] At this point we divided the main category D into three single items (motivation of students, support personal development of students and improving the social skills of students). This division got necessary because of the concreteness of the described types of labwork. Thus we now have 7 main objectives. But now, 3/7 of all objectives have a social dimension.

5



The value **2** is 'very useful',
1 is 'useful',
0 is 'can't decide',
-1 is 'less useful',
-2 is 'not useful'

Some level-, subject- and country sample specific differences get visible looking deeper into the data set.

- **Experiments using modern technologies** are judged as **less useful for the university level** than for the school level. Especially the usefulness for improving social competencies and for evaluation of students' knowledge is seen negatively. With focus on the country samples the data show that the teachers asked in Germany and in Denmark judge the use of modern technologies for reaching the main objectives as less useful.
- **Strongly guided experiments** are judged as **more useful at the school level**, especially for reaching aims with a social dimension.
- **Demonstration experiments** are judged less useful than the other types of labwork. However, they are seen as **useful for reaching the first three objectives at the school level** - to link theory and practice, to learn experimental skills and to learn methods of scientific thinking.

4 . 6 Discussion and Conclusions

With the results of this study, according to the problem of multi-culturality and multi-linguality, and the limited data set, we only can give a rough overview and special tendencies. For instance, it is interesting that the differences between levels and subjects could be identified within the two first parts of the questionnaire. The objective 'to learn experimental skills' seems to be more important at the university level than at the school level. The objective 'to foster motivation, personal development and social competence' seems to be more important at the school level than at the university level. The subject of Biology attracts more than the others to an objective 'to develop scientific thinking'.

The objectives formulated, ranked and judged by teachers and categories abstracted by us for labwork instruction could be described. For being able to abstract hypotheses about the achievement of these objectives further investigations are necessary. The first step into this direction is a special case study running in the German group of the project.

Chapter 5

CASE STUDIES ON TYPICAL AND INNOVATIVE LABWORK IN FIVE COUNTRIES

Dimitris Psillos, Hans Niedderer

The work on the Case Studies has been carried out in each group of the consortium. Researchers involved in each Case Study are referred to in the tables 1, 2, 3 and 4 of this chapter. The co-ordination of the Case Studies and the elaboration of a strategy for progressive elaboration of the reports has been the responsibility of the co-ordinators, D. Psillos, H. Niedderer who gained considerably by interactions with all researchers involved in Case Studies. Besides, M. Vicentini has contributed substantially at the initial phases of the coordination.

5 . 1. Introduction

As much as 23 Case Studies (hereafter called CS) have been carried out in six participating groups, allowing for an in-depth investigation in a variety of contexts of how students' understandings of several aspects of scientific knowledge and inquiry may be facilitated by different forms of labwork. Still it has not been possible to cover all possible contexts in upper secondary and University education. There are more CSs at university level than at secondary education, more in Physics than in other scientific disciplines. Even with such limitations the great number of co-ordinated CSs has allowed for new foci and meanings to be assigned to the research questions regarding the relationships between student engagement in various forms of labwork and different aspects of scientific understanding and has revealed a variety of teaching-learning objectives which may be pursued by labwork.

In the project *'LABWORK IN SCIENCE EDUCATION* ' (LSE), the Case Study has been adopted as a multifaceted research methodology potentially capable of examining the influence of certain organisational and personal factors on labwork and of identifying, describing and documenting students' actions and cognitive processes taking place during labwork. Therefore, the LSE CSs results are to be seen as important indications regarding the description and interrelations of complex factors affecting labwork effectiveness rather than as a way to draw conclusions that can be easily generalised to other situations.

For reasons of space, code numbers are used for each CS : the first letters are the initials of the country and a number is attributed to each CS.

5 . 2 The structure of the case-studies

In Figure 1 we present a model of a CS structure.

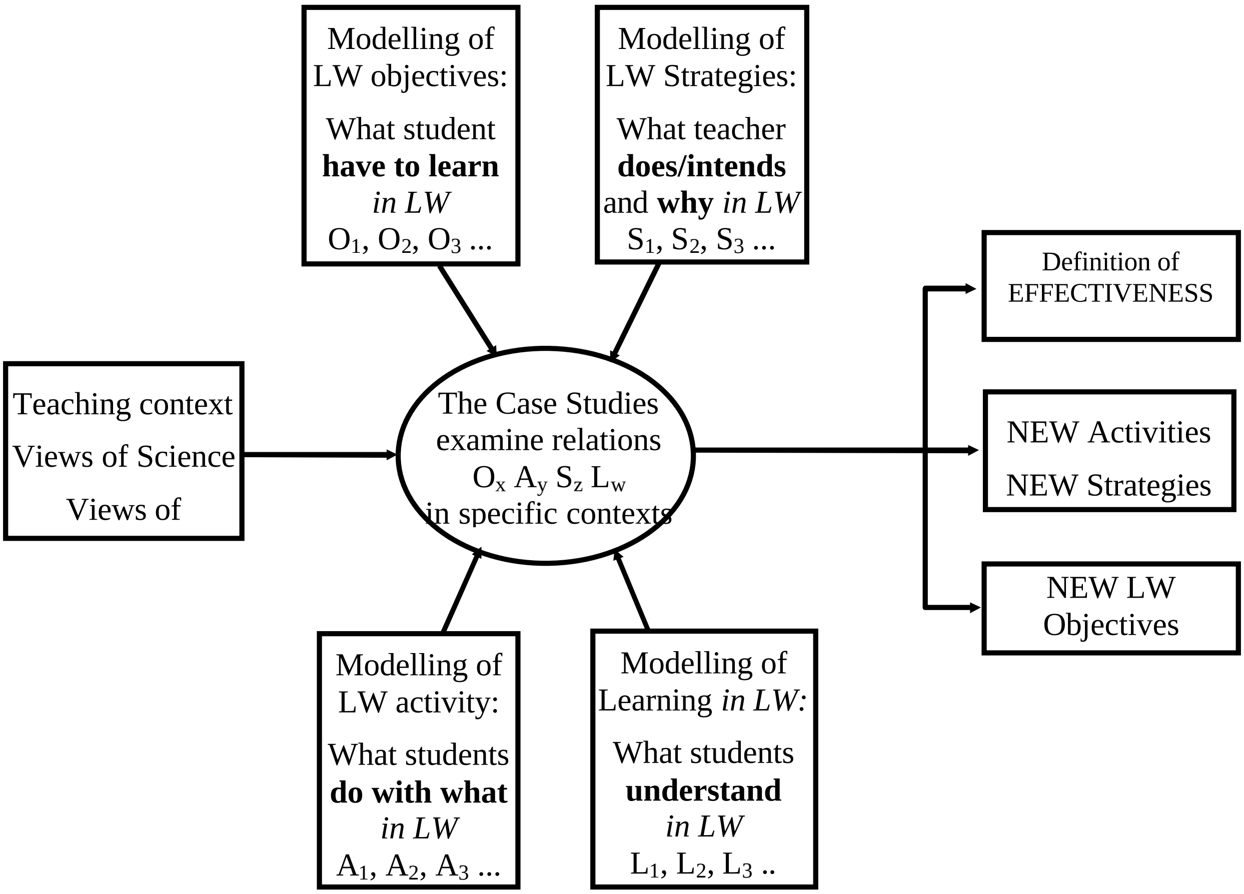


Figure 1 : Structure and research foci of the Case Studies

The figure is no more than a pictorial representation of important educational issues relevant to CSs which illustrates systematically possible interconnections between planned or expected activities for the contribution of CSs to our understanding of labwork. The model is presented in a way which potentially opens up interpretations and new questions surrounding the various components as it may seen in this and the next chapter . While this model may represent components and activities of one CS, not every CS may be described or focus on all parts of the model. For example, a number of CSs focus on students' intellectual or manipulative activities during labwork; some CS focus on students' evolution and acquisition of conceptual knowledge following labwork.

In line with the above model we developed a strategy for the progressive elaboration of the quantity and quality of the required information out of the CSs. As part of such a strategy, in collaboration with the various LSE groups, we developed a special report scheme in order to acquire and code information from the various CSs. What is more, the scheme helped researchers in sharpening their focus and clarifying their assumptions and design of their own CS. One position underlying the development of the scheme was that it should facilitate the linking of particularistic elements of the CSs with broader issues on labwork.

In other words, each CS should make explicit in what way and why their piece of labwork and research questions are worth investigation and reporting. A second position is that reports and corresponding CSs should carefully differentiate between teaching context and research design. A third position is that the contextualised information needed in the present Project should include researchers' views about: a) Science, b) learning Science in labwork, c) teaching labwork.
The report scheme consists of three main parts focusing on the context of the CSs, the research design and the products.
In the first part, comprising two main items, investigators are asked to provide information related to the unique features of the context in which they carry out the CSs as well as to link their work to the broader issues which are the concern of labwork. The second part focuses on research design seeking to elicit any special design features of the study. The third part includes several items focusing on the results and conclusions coming out of the CSs. A special feature of the scheme is that it asks for specific recommendations seeking to relate research with educational policy in the context of broad aims of LSE.

In the present chapter we focus on the contextual factors and the types of labwork realised and investigated in the CS. In the next chapter we focus on issues regarding laboratory effectiveness and laboratory objectives coming out of the various CSs. As it may be seen from Figure 1, three types of contextual factors have been particularly prominent in the various CSs namely, the views about science, learning assumptions and the teaching context. These are successively presented in the following sessions.

5 . 3 On the views about science espoused in the case-studies

Any approach to teaching and learning Science is influenced by epistemological considerations concerning the structure and the object of the scientific knowledge to be taught. This is particularly true for the role of labwork activities in Science teaching.
In fact, in the development of an experimental Science, there is a continuous and complex interplay in the experimental work (questions to be answered empirically, the intention of the experiment, the procedures of data collection, the analysis of data), between the theoretical framework (theories and models but also ontological beliefs), the technological apparatus and techniques available at the time of the experiment.

In this context, on the one hand the CSs depart from empirical inductivist positions but on the other they do not share common epistemological assumptions. As a matter of fact in research on labwork, including recent reviews one can hardly find discussions on underlying epistemological positions. Such a discussion has emerged at various levels in the CSs; in some cases as GB1,GB2, GB3, FC3, FC6, FD5, I2, GR4 the epistemological positions of the researchers are emphasised and broadly outlined. In other cases epistemological assumptions are implicitly related to the piece of labwork which is investigated.

5 . 4 Assumptions on learning science underlying the case-studies

Broadly speaking the CSs seem to share the view that constructivist views of cognition and learning evolving in Science Education during the last twenty years have a potential for informing researchers who try to understand teaching and learning in the laboratory. The way of describing students' knowledge and learning in existing laboratory situations as well as the design and development of special tasks and experimental sequences in innovative labwork are particularly influenced by the researchers learning assumptions. Several CSs emphasise the role of prior domain-specific knowledge in learning science and the active construction of meaning by students when interacting both with material situations and/or during social interactions between teachers and students during labwork. Not only knowledge construction and conceptual evolution but the use that students make of their own or new scientific knowledge in labwork is among the foci of several CSs which search for the complex cognitive processes taking place during students' engagement in labwork. For example, some CSs investigate students' individual conceptual evolution in the course of an experimental teaching sequence; other CSs focus on how students may or may not link manipulation of equipment with conceptual models or the purpose of experimentation or see labwork as a set of disconnected actions to be followed. Conceptual and procedural knowledge is involved in such situations which often are considered separately in research and teaching in labwork. In LSE CSs a shared assumption is that these two types of knowledge are intertwined and both are employed if the students are engaged in meaningful experimental activities.

5 . 5. Teaching context : several levels of labwork

The planning of teaching activities concerning experimental work while being related on one side with views about Science and on the other with learning assumptions , which teachers/designers hold, may be also framed by the context in which the activities take place. For instance the school context may dictate a traditional content for the labwork activities or a freedom of choice of the contents sequences may be allowed. It appears that at secondary education several of the CSs such as FC3 and FC6 ascribe to the restrictions of the educational context whereas at the university level there are several degrees of freedom, for example GR2, FD5, I2 allowing for innovation and experimentation. Perhaps this is one reason why several of the CSs are concerned with University rather than secondary education labwork. As matter of fact, this is an important development since University labwork often is far beyond accepting innovations.

The CSs concern a particular lab activity, or a sequence of activities. The CSs falling in the first category, such as GB1, GE1, FC7, FD1, FC3, GR4, attempt to investigate learning process related to particular instances of applications of teaching strategies or new technologies in Labwork. The detailed, extensive study of such specific instances provide a wealth of information at several levels revealing, for example, implicit assumptions inherent in exemplary illustration of a scientific procedures (FD2), levels of an explanation demanded by the students (FC6), and provide evidence on the use of students' personal knowledge when they are engaged in specific tasks (GE2).

In the second category the activity may be planned in a series of lectures-practical activities succeeding each other or in a setting in which the experimental work is intertwined with the communication of conceptual/theoretical information Such labwork involves experimental teaching sequences which involve learning of scientific models or strategies not acquired by involvement in a single experimental task. Extended pieces of Labwork are structured in a coherent way according to specific design criteria revealing and contributing to the identification of new patterns for Labwork. For example in FD5 the curriculum refers to four semesters of labwork, in I2 a year long teaching sequence is experimentally supported, in FC1 and GR1 simulated models and hands-on experiments have been integrated in medium level teaching sequences, while in GE3 a whole sequence of labwork sessions has been developed in mechanics, integrating MBL and MBS systems.

5 . 6 A suggested classification of the LSE Case-studies

The LSE Project has adopted a view, which widens labwork from the typical hands-on small group work or large class demonstrations of experiments to other types of labwork in order to explore the potentialities of new technologies and forms of organisation that focus on aspects of scientific experimentation. In the following sections we describe and classify the 23 CSs in four categories according to the dominant type of labwork which is employed in each one of them. In each category we present Tables including the title , the authors and the code number of the CSs used within the LSE Project.

i) 'Typical' Labwork based on small group work and hands-on experiments

In LSE CSs, labwork may imply that students may carry out experimental work themselves, or watch a teacher carrying it out using standard laboratory apparatus. Six CSs fall in this category as it appears in Table 1.

TABLE 1	***Labwork based on small group work and hands-on experiments***
	<u>1.1 Case Studies involving existing situations</u> **HALLER K., WELZEL M. & S. von AUFSCHNAITER:** *Development of situated cognition during labwork activities of University students* **GE1** **SÉRÉ, M. G & BENEY, M.** *Students' intellectual activities during stereotypical labwork at Undergraduate level* **FD2** **BECU -ROBINAULT K.** *Introduction of the power concept (traditional labwork)* **FC3** **Le MARÉCHAL J. F.** Approaching the concept of chemical equation through labwork activities. **FC6**
	<u>1.2 Case Studies involving integrated experimental sequences</u> **KARIOTOGLOU P.** *Investigating aspects of an innovative experimental teaching sequence: the case of fluids* **GR2** **ALBANESE A., CIGOGNETTI C., DANHONI NEVES M.C. & VICENTINI M.** *Experiments for an innovative approach to Physics* **I2**

Typical labwork may or may not necessarily be linked to a lecture, since theoretical information is summarised either in the labsheet or presented orally if judged as necessary by the teacher. Among the intended tasks, measurement and data processing take a large place. Such a typical labwork is spread out all around the countries (see chapter 2) and relies heavily on a labguide containing information and instruction for the students. What the students do and how their cognition develops in such a strictly guided environment is a main focus of FD2 and GE1 aiming at investigating ways for improving existing University labwork. While respecting the constraints of the educational system the next two CSs , FC3 and FC6, focus on changing the labsheets with specific questions related to linking the world of objects and events, models and theories.

An interesting variation concerning typical labwork are experimental teaching sequences based on innovations at the knowledge representation level which is different from usual approaches revealing new links between the models to be taught and corresponding experimental field. This is the case with I2, in which a unifying approach to different chapters of Physics both at the phenomenological level and at the explanatory level is supported by a variety of experimental situations and with GR2 in which an innovative educational reconstruction of conceptual knowledge is experimentally supported.

ii) Labwork based on integrated use of new technology

New technology can be integrated into labwork in a variety of ways:

- The computer is used:
    - for data collection (MBL), in GR1, FD1, GE2, and GE3
    - for analysis and graphical representation of data, in FD1, GE2, and GE3, GR3
    - for model building with model building software (MBS, e.g. STELLA), in GE2, and GE3
    - for simulation of a physical model, in FC1,
    - for demonstration of an interactive microscopic model for electrical polarisation, in GR3,
    - for communication during labwork via network, in FC7.

and for combinations of these types of uses.

- Video clips are produced and used for demonstration of a microscopic model for heat or for sound, together with connections to real world phenomena and experiments, in FC4 and FC5.
-

TABLE 2	***Labwork based on integrated use of new technology***
	2.1 Case Studies involving information taken from integrated use of computer **BISDIKIAN, G, PSILLOS D.** *A computer based approach to relate graphs and Physics: the case of heat and temperature* **GR1** **BEAUFILS, D.** *Knowledge and know-how involved in MBL activities* **FD1** **HUCKE L. & FISCHER H. E.** *The link of theory and practice in traditional and in computer-based University laboratory experiments in Germany* **GE2** **SANDER, F., NIEDDERER H. & SCHECKER H.** *Learning processes in computer-based Physics labwork in a course on Newtonian mechanics* **GE3** **BUTY C.** *Modelling in geometrical optics using a microcomputer* **FC1** **BARBAS A. & PSILLOS D.** *Evolution of mental models and reasoning patterns in explaining charged-uncharged bodies interactions* **GR3** **BECU-ROBINAULT K. & TIBERGHIEN A.** *Introduction of the power concept (communication via a network)* **FC7**
	2.2. Case Studies involving use of video films **ROBLES M.Q & Le MARECHAL J.F.** *Use of modern technologies in introducing a particular model with experiments on gas expansion: analysing the influence of the order of the introduction of new knowledge* **FC4** **ROBLES A. & Le MARECHAL J.F.** *Teaching sound propagation with videos*

	for promising use of data bank of experimental demonstrations on CD-ROM **FC5**

iii) Open-ended labwork

In another type of labwork full instructions may not be given to the students. Instead the students are required to make some decisions for themselves as to how to proceed. This is the approach taken in FD3, GB2, GB3, which involve students in various types of types of projects in a laboratory and open field context. An important issue concerning all these CSs is what scientific procedures are students required to learn besides conceptual knowledge. Besides an open issue is whether epistemological information relating to the processes and strategies of investigation of the scientists should be explicitly presented to the students as advance organisers of their investigative work at different contexts. This is the object of FD5. Finally a key question in whether scientific knowledge and procedures learned in a school like context may be effectively applied to a workplace involving complex technological settings. This is the object of one CS namely FC7.

TABLE 3	***Open-ended labwork***
	GUILLON, A. & SÉRÉ, M.G. *Labwork curriculum aimed at teaching physicists ' methods at Undergraduate level.* **FD5** **LEWIS J.** *The use of mini-projects in preparing students for independent open-ended investigative labwork* **GB2** **GUILLON, A. & SÉRÉ, M.G.** *Open-ended projects achieved by students during the second year of Undergraduate studies* **FD3** **RYDER J.** *Data collection and interpretation during undergraduate field work in earth sciences* **GB3** **VEILLARD L.** *Role of two types of labwork context in learning about technical vocational knowledge* **FC2**

iv) Case Studies involving specific phases and different representations of labwork
It is recognised that students' activities are interrelated when they are engaged in scientific investigation. It is also accepted that labwork may focus on specific activities or phases of labwork which do not involve, for example, planning or data recording. The first two CSs in this category (GB1 and GR4) deal with students' learning about data processing, about knowing how data might be collected and the errors likely to be associated with it and the roles and functions of measurement in Science, focusing on the relation between the concrete measurement process and abstracts models of that process. These issues are studied by the use of secondary data or in pre-laboratory teaching.

TABLE 4	***Case Studies involving phases / representations of Labwork***
	i. Case Studies involving phases and representations of Labwork **LEACH, J.** The use of secondary data in teaching about data analysis in a first year undergraduate biochemistry course **GB1** **EVANGELINOS D. PSILLOS D. & VALASSIADES O.** An introduction of the students to measurement: A metrological approach **GR4** **--** **ii. Case Studies involving representations of Labwork** **BANDIERA M., ROSSI A., TORRACCA E.** *Textbook as a source of experiments* **I1**

Finally, an important yet not widely investigated issue is the image of experimental activity conveyed by textbooks. This is investigated in a CS (I1) which has also been included in the present chapter.

CHAPTER 6

EFFECTIVENESS OF LABWORK AS DEFINED FROM CASE-STUDIES OF DIFFERENT TYPES OF LABWORK

Dimitris Psillos, Hans Niedderer, Marie-Geneviève Séré

6 . 1 A model of laboratory effectiveness

The different Case-studies (referred as CS) carefully distinguish teaching contexts and research design. Among the elements characterising the teaching context, are objectives, in terms of knowledge, cognitive constructions and models to be acquired by students. However, in addition, a valuable part of the results from case-studies concern students' constructions during labwork and on the factors determining what they actually do and understand. Thus the CSs have set out for the elaboration of several types of effectiveness of labwork related to specific contexts, beyond the assessment before - after which is usually carried out during ordinary teaching.

On the one hand several CS employ widely used methods of obtaining learning outcomes including qualitative data. Such methods involve pre-post-analysis of tests or other instruments, like concept maps, questionnaires or analysis of students' written reports. Interviews are used to obtain data which are, often, triangulated with the data from other sources. This is the way of analysing the effects of labwork adopted in a number of CS e.g. GB1, FD3, GR3, GE2, GR2. Students conceptual pathways are monitored by similar methods in certain case-studies like GE3 and GR2. We suggest that such forms of obtaining and analysing results are related to one type of laboratory outcomes. Judgements on the quality of labwork which are based on achievements of expected learning in relation to the objectives represent one type of labwork effectiveness which we call ***effectiveness 1***.

On the other hand, a number of CSs are focusing on describing and classifying student activities during the various phases of labwork. These CSs attempt to find out relations between a specific context and different kinds of student actual labwork activities, for instance, how students are engaged in handling apparatus, measurements, or how do they employ their scientific knowledge in measurement. In a number of CSs such as FD2, FC6, methods used involve analysis of data from ongoing activities during labwork, in the form of audio- or video-taping followed by transcriptions, paper and pencil tasks and student assignments. Certainly, there are different categorisations of students' activities during labwork in the various research groups involved in LSE which depend on their assumptions about learning, their epistemological positions and specific research focus. One new method was developed which has been applied to FC1, GE1, GE2.This method focus on effectiveness 1 since it deals with what the students are doing during the labwork sessions. Briefly, the method involves fast analysis of videotapes from labwork and gives some interesting results about effectiveness of different kinds of lab situations in regard to intended use of knowledge during these labwork activities. We suggest that such forms of obtaining and analysing results, showing what the students do and what they understand out of their activities, are related to a distinctive outcome of laboratory work. Judgements on the quality of labwork on the basis of such outcomes are linked to a specific type of effectiveness which we call ***effectiveness 2.***

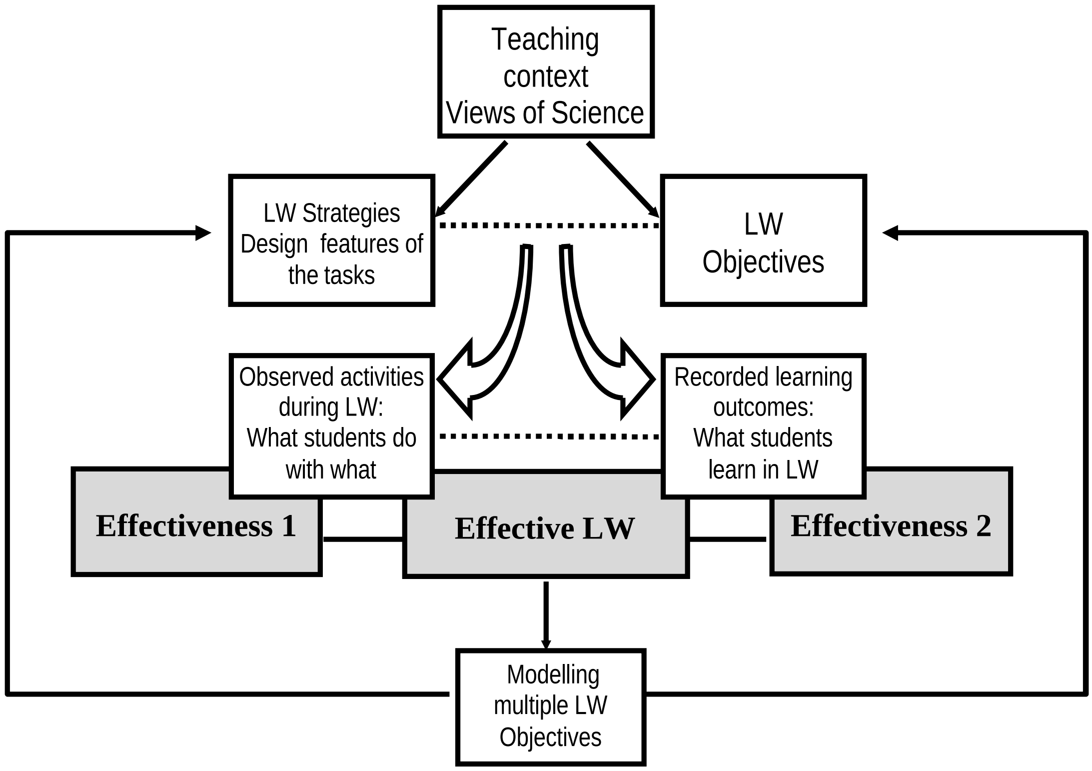


Figure 6.1: A model of labwork effectiveness

A model representing laboratory effectiveness as related to the design of a CS is illustrated in Figure 6.1. Some remarks follow. At first, the relation between the use of conceptual, procedural, epistemological, knowledge during labwork and learning outcomes after labwork is a complex one, which is currently under investigation in science education and the present CSs. This unknown relation is denoted by the dotted line between the boxes representing effectiveness 1 and effectiveness 2. Second, acquisitions which are signs of effectiveness 2, are in a descending chronological order with student constructions during labwork which are signs of effectiveness 1. We argue that descending chronological order does not necessarily imply a causal dependency between these two shorts of outcomes. Furthermore effectiveness 2 does not come after effectiveness 1 one piece of labwork simply may be effective from two points of view. This is why the boxes of effectiveness 1 and 2 are placed at the same level while usually they are placed one after the other. Finally, in the proposed model one CS may focus either on effectiveness 1 or on effectiveness 2 or both. Depending on the CS the box on effectiveness 1 or 2 may be smaller or larger or not exist at all.

We suggest that a twofold effectiveness of the type described above is a very specific feature of the practical character of labwork among the various teaching activities in science education and, possibly, in other fields beyond science education. In fact as soon

as students' activities are done in relation a given problem statement, a labsheet or other types of instructions and can be observed, effectiveness 1 can be considered. When these activities are included in a teaching sequence effectiveness 2 can also be considered.
In the model the last box suggests that results from one CS contribute to the specification and development of new objectives for labwork. In other words the model implies an iterative cycle of research and development as a means to improving labwork effectiveness in various contexts. This is represented by the feedback loops from the new objectives back to the development of new strategies and the clarification of the initially set objectives.

Applying the suggested model to the large pool of the 23 CSs allows for a different level beyond the determination of new objectives for a single piece of labwork. Drawing together new objectives from several CSs allows us to approach objectives in terms of modelling . This issue is discussed in section six after the discussion of results from small group work and hands on experiments, labwork based on the integrated use of new technologies, open ended labwork, and specific forms of labwork .

6 . 2 Labwork based on small group work and hands-on experiments : summary of results.

The effectiveness of standard laboratory work in science education has been investigated in six case studies. Despite the variety in the contexts, level of teaching learning and epistemological assumptions which affect task design, certain trends may be detected. The emerging picture is that in quite different contexts at secondary and university education manipulating apparatus and measuring are dominant activities occupying much of students time during laboratory sessions (GE3, FC3). In effect it appears that the activity that surrounds the practice of the experiment in labwork may be more difficult for students than the experiments themselves (FC6). In experimental situations involving quantitative analysis, measuring appears as the richest activity concerning the use of a variety of knowledge relative both to the devices (experimental settings), to concepts and the enlargement of the experimental field (FC3, FD2). In such situations systematic recording with specially developed tools suggested that theoretical and technical knowledge was not employed very often (15% time) while the use of mathematics knowledge was rather rare during laboratory sessions (GE3).

Several CSs point out that the context of experimenting in itself is not sufficient to influence students' actions and conceptualization of the situation which are strongly affected by the labguides. Use of labguides were the third most frequent activity after measuring and manipulation of apparatus a result which was expected in highly structured labwork involving quantitative analysis (GE1). Despite the high structure of standard laboratory situations it appears that students have a certain degree of autonomy which points out the importance of labguides in conveying goals and imposing student actions. As a matter of fact it appears that labguides are fatally implicit for several pieces of knowledge (FD2, FC3, FC4,) the determination of which is not obvious at all and demands considerable research.

Addressing the question of effectiveness 1 implies investigating, on the one hand, what the students do during experimentation and, on the other hand, how their actions and the procedures which they employ during experimentation are, or are not, intertwined with theoretical knowledge on which the experimental design draws upon. Results from various perspectives of the LSE research groups suggest that students did not think so much of the theoretical explanations offered in their guidebook or in the associated lectures even if the experiment was considered as an easy one or that students do not use measurements to verify hypothesis and refrain from making links between objects, events and physics model or theories. A notable result is that expert teachers performing the same experiments, in the same line with students, use as less as possible either their own or the text book theoretical knowledge. Thus from doing experiments students and teachers may develop rules of action but not conceptual learning (FD2).

One important issue concerns the role of specially developed labguides and tasks for enhancing the use of physics knowledge which was among the objectives of (FC3, FC6, GE1, GR2). Results (GE1) suggest that in the case of specially developed labguide the use of physics knowledge was twice as high as with ordinary ones even in stereotypical labwork. This brings up again the issue of linking on the one hand the various aspects of science knowledge with facets of experimental procedures. It seems that (FC3, FC6) relating the experiment, the measurements and the concepts are pursued by students only if the guides require so.

Concerning the development of experimental teaching sequences, the previous results bring about the question of integrating the experimental activities with the underlying conceptual models and at the same time respecting students' prior knowledge. In both GR2 and I2 the relative emphasis on qualitative experimental activities aiming at conceptual change seem to produce reasonable results. This is more so when experimental results are discussed either in relation to models and theories more than measurements(I2) or are conflicting with students' domain knowledge (GR2). Certainly students difficulties in experimental procedures which, for example, were noted in GR2 may hinder the effectiveness of labwork. Moreover several experiments do not necessarily "speak for themselves" to the students and may stimulate the development of alternative interpretations of experimental observations (GR2).

6 . 3. Labwork based on integrated use of new technology : summary of results

Results of empirical research show a lot of positive effects out of the use of this new technology, but also some negative effects and open problems. The following points are aiming at formulating generalised hypotheses based on more specific results of several single case studies.

- In all case studies, learning to use the computer software in general was a rather small problem and solved after two or three applications. Specific problems however are reported for the use of specific software, e.g. with the syntax to be used in mathematical formula (FD1).
- The capability of the computer screen to present real-time graphical information turned out to be a key function in allowing students to connect the phenomena with what the graphs represent (GR1; also in FD1, GE2 and GE3)
- Using simulations of microscopic models to explain phenomena during labwork - either as computer simulations (GR3,) or as video films (FC4, FC5) - can contribute a lot to conceptual change.

- Using the computer for model building being integrated into labwork stimulates students to talk more about the physics background of a specific lab situation than most other contexts of labwork (GE2, GE3, FC1). But the link of theory to objects and events of the real world is not automatically improved at the same time.
- An important difficulty consists in taking into account information given by the statistical method concerning experimental**):** numerical values of physical quantities are generally given without unity and with an inconsistent number of figures (FD1). Therefore, some information on statistical processing of experimental uncertainties, data logging, automatic modelling and numerical solving of differential equations should be included in sciences courses (in close relation with mathematics).
- According to the results of concept maps (GE2), the performance of the experiment caused only few changes in the students' knowledge structure related to theoretical and physical concepts, but several changes in the students' knowledge structure related to experimental details. The small differences in concept maps before and after labwork are often related to a more detailed description of methodological or technical aspects.
- Special didactical approaches, which combine labwork with interactive computer simulations or microscopic model and tasks for students of a 'thinking type', like prediction and explanation, can foster conceptual change (GR3, GE3; FC4, FC5).
- The collaboration, when students work in small group during labwork, in particular sharing a same experimental device and a same labsheet, can help students to have common references and then reinforce their collaboration. Analysing ag labwork on a distance and using a computer network is a relevant situation to study the role of the resources available to the students in the collaboration during labwork (FC7).

6 . 4. Open-ended labwork : summary of results

The effectiveness of open ended laboratory work in science education has been investigated in five case studies. As it appears from these CS open ended labwork is focusing on students' understanding of scientific procedures in a more focused way than the standard labwork, without neglecting the acquisition of conceptual models. This implies that assessment of open ended labwork depends on the specific expectation embedded in a laboratory project. Moreover, such an assessment depends on the type of modelling of scientific procedures and practices followed by practising scientists so as to become teachable.

Modelling scientific practices is not an easy task. For example, FD5 achieved to model the physicists underlying epistemological knowledge in terms of four models mathematical, simulated, theoretical, experimental and confrontation between experimental data and these models. Student managed to discriminate between process at a moderate level but had difficulties in relating a particular model to a process. A low retrieval of epistemological knowledge was noted in the first phase of the three semester long special curriculum, a situation which was considerably improved after this sequence.
How important is the clarification of aimed scientific procedures is shown by GB3. Mini projects in biology were successful in achievement of educational aims, namely to prepare the students for final year projects, but not in achievement of practical aims, which were the understanding of the underlying conceptual knowledge in genetics. The major reason for such a result was that there were conflicting messages from the instructors to the students or that there was not a balanced approach of these two aims. As a result negative attitudes were developed by the student towards mini projects.

The influence of meta-knowledge in organising projects is dependent on students' familiarity of the problem to be investigated. From FD3 it appears that students resort to meta-knowledge when the problem is unknown to them. A problem noted here is not the succession of different steps in an experimental project but their co-ordination. Results from FD3 suggest the epistemological frame taught during three semesters was operative in facilitating students linking of various phases of open ended projects. Beyond the deeper understanding of the mechanism involved in the development of experiments, two important points were raised. There is a strong difference in the use of uncertainties and orders of magnitude when taken into account before experimentation i.e. in projects or after experimentation i.e conventional labwork session. In the first case, both participate in decisions and so this allows a more fruitful use.

How to use scientific knowledge in a geological field was also the least elaborated aim in CS GB3 while learning technical skills of geological mapping were better elaborated. Further on, field work proved very valuable for the students to bring together previously detached pieces of knowledge taught in the various courses. However, the students used their knowledge in a rather fragmentary "local" way in the field cite and tended to design the investigations to "see what happens" rather than establishing strong links with geological theories. A striking finding in this CS was the readiness with which first year geological students stated that different conclusions can legitimately arise from the same data as compared to students from the same university who were studying biochemistry. A field environment proved unique in learning things like navigation in a field which is virtually impossible to reenact in the laboratory. This Case Study suggests that experimentation within a labwork environment cannot cover a number of activities of practising scientists, especially in disciplines like Geology and Biology. A similar result came out from FC2 for practising engineers. On the other hand it appears that knowledge, methods and techniques learned in a vocational school are not directly used by a student in a working situation. Instead the trainee used resources given by the firm he did his project.

6 . 5 Case-studies involving specific phases and different representations of labwork : summary of results

- The two CS, GB1,GR4, note difficulties of students to come to a valid understanding of measurements, their uncertainties and their relation to theory.
- During the use of secondary data (GB1), the teachers interviewed did not articulate a clear rationale for what the students were intended to learn during the teaching activity. It is therefore recommended that labwork teaching activities which aim to teach about procedures are designed so that students' attention is focused upon the underlying rationale of the procedures used.
- Also during the use of secondary data (GB1), students overwhelmingly viewed the teaching activity as a successful learning experience. However, data from both surveys and interviews suggests that many students did not hold clear understandings about how kinetic data might be collected, errors that might be associated with kinetic data, and the significance of calculated constants in terms of a model of enzyme kinetics.
- Also during the use of secondary data (GB1), specifically, as many as 52% of students did not show evidence of knowing how kinetic data might be collected, and a further 36% of students made ambiguous statements on this issue. Other similar results lead to the conclusion, that this teaching activity was not particularly successful in teaching

about data analysis. It is therefore recommended that university curricula address explicitly the basis for standard data processing techniques with students at an early stage, if students are expected to understand the rationale behind such techniques.

- In GR4, a special approach was developed to overcome students' problems to understand data analysis and measurement. Afterwards, students were able to successfully make probabilistic interpretations of single measurements, which is not possible in classical approaches. In repeated measurement situations, students were able to use standard deviation as a measure of uncertainty, but still had difficulties assigning the taught probabilistic meaning to it.

Finally, from I1 it emerges that textbooks convey an image of science, which directly refers to natural objects and/or phenomena, which tends to sustain rote learning rather than illustrating the role of experimental activities (observation and experiments) in constructing scientific knowledge; it also tends to discourage personal involvement and speculative attitude; and it prevails facts over ideas.

6. 6 A model of organisation of laboratory objectives

The results concerning *Effectiveness* allow to go back to the identification and formulation of objectives. Some of them, in current practice, are generally implicit and seldom reached through the usual tasks and steps of an experimental process.
As demonstrated before, the set of case-studies results in a renewed list of objectives. In fact it is more than a list, because mutual links and influences exist between those attached to a given task. For instance data processing can be taught as a routine. But it may be also the opportunity for epistemological teaching. Similarly, modelling is a multifaceted task that teachers can devote to very different objectives. Respecting the classification of conceptual, procedural and epistemological objectives, structure and organisation exist in the CS list of objectives. We call that a model that further research will have to develop.

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4 . CONCLUSIONS AND POLICY IMPLICATIONS

Introduction

The objectives of the project within the general movement of research in science education

Since the late '70s the specific contribution of labwork to understanding science has been studied more and more. Manipulating real objects, modelling them, understanding the respective places of theory and experiment in doing science, acquiring the conceptual basis of specific skills, are recognised as a significant part of understanding science. Consequently labwork has been a major focus of research. However, it remains open to question whether labwork activities are necessary in the processes of teaching and learning at school and university, or whether the possible role of labwork in promoting learning is overstated. The answer to this question may have far-reaching national and international political and economic consequences.

In the past, research has been done with the intention of developing innovative forms of labwork which are especially effective for learning. The results of these investigations are diverse. Some of them show that labwork is, or can be, useful in promoting learning. For example a long-term investigation of students' learning of biology shows that the use of labwork has a long lasting positive effect on students' abilities to learn content, as well as of their motivation for the subject of biology. But other studies suggest that students' understanding is often not improved through labwork.

Recently research has started to address the potential of specific learning environments and especially new technologies in promoting students' learning. It is generally agreed that the use of new tools such as computers during labwork changes the type of activities carried out by students. Thus new possible learning aims were formulated and the corresponding objectives of labwork have now to be studied anew. Different studies addressed specifically the influence of computer activities introduced in labwork, alongside methods to identify teachers' expectations about students' learning during labwork.

These diverse and sometimes contradictory findings on the effectiveness of labwork learning environments show a lack of clarity concerning the nature and the complexity of the objectives that it is possible to address during labwork. It is in this research context that the need was felt at European level to put efforts together to address the problem of effectiveness of labwork activities in Science Education.

Recently another direction of research started to provoke interest amongst teachers and researchers alike. It has stemmed from a broader view of the possible objectives of science education, recognising that science education has not only an influence on the professional life of future scientists, but also a very important role to play in the general education of future non- scientists. This corresponds to a general goal for the present and future task of science Education in Europe : to address every student, not only the elite. The challenge is thus not only to improve science teaching for future scientists, but also to prepare all citizens for responsible and informed decision making in a scientific and technological world.

This line of research is addressed in the literature under the heading of *'images of science'*. This general term 'images' means representations of the nature of the products of science (laws, theories etc.) as well as images of scientists' activities, as well as the public use of science. It addresses on the one hand students' ideas about science developed through their studies of science, and on the other hand the ideas about science used by teachers to inform their teaching. There is a good deal of evidence that the images of science drawn upon by many students during labwork constrain their performance. For example, students' understanding of the nature of data result in them taking inappropriate actions during labwork that involves measuring physical quantities. Similarly, university students working on open-ended investigations sometimes draw upon understandings of the relationships between data and knowledge claims that result in inappropriate actions being taken. In terms of research addressing teachers' images of science, previous research has tended to focus more upon general ideas about science than the specific example of the role of experimentation in science. A new direction for research is therefore the investigation of people's understanding of the methods of science, i.e. the ways in which scientists work, collect data, formulate hypotheses and develop theoretical models focusing upon aspects related to the role of experiments in labwork.

The state of the art of research in 1995 thus pointed to a need for specific research aimed at
- producing a better conceptualisation of the aims and purposes of labwork;
- improving students' understanding of scientific content and methods;
- elaborating a grid of criteria around which the effectiveness of labwork might be evaluated;
- building innovative teaching sequences using empirical or computer-based labwork to address these criteria.

All seven groups in the project were involved in this enterprise. Given the expertise of the different participants, it was possible to use several methods to address research questions:

- Surveys at European level: three surveys were planned, addressing current labwork practices, students' and teachers' images of science, and teachers' objectives for labwork;
- Analysis of labwork sheets from across Europe in terms of a common grid, called 'The map of variety of labwork';
- 23 case-studies on specific issues, to generate illustrative material and to draw upon when developing recommendations for effectiveness.

The results are presented in the various Working Papers (see annexes), and summarised in part 3 of the report. In this part, we focus on the conclusions themselves (chapter 1) and the resulting recommendations (chapter 2) which allow us to identify research needs in Europe (chapter 3).

Chapter 1

Main research results and conclusions

Introduction

In this chapter we gather conclusions and we proceed from the *'existing'* [current practices in Europe, present teachers' objectives] to the *'possible'* [labwork should aim at a broader range of objectives among which relevant links theory-practice and images of science to be drawn upon].
Then we draw conclusions concerning the effectiveness of labwork, given the fact that, in the preceding part reporting the main results of the project *'Labwork in science Education'*, effectiveness has been demonstrated to be a complex issue. In fact, through labwork, learning objectives are aimed at (effectiveness 1). But in addition, during labwork, activity (thinking, doing, understanding science) has got a specific value (effectiveness 2). What students do constitutes an aim in itself. So both types of effectiveness are to be considered in this chapter. Finally, tools developed to inform teaching and research during the project are presented. They may be useful for researchers and teachers in charge of improving labwork.

1 . 1 Educational organisation as a framework for labwork

To better understand the practice of labwork, information on the educational organisation of science teaching, from primary school to the upper secondary school, has been collected in each Partner's country (Denmark, France, Germany, Great Britain, Greece, Italy) and from Spain. The analysis of this information shows that, at *primary school level*, science teaching is quite rare in almost all the countries for similar reasons. However several countries are currently trying to develop science teaching at this level.

At the *lower secondary school level*, the situation between countries is very diverse. For example, in England, Italy and Spain the curriculum refers to "science", and in other countries like France, Germany, Greece it refers to subject disciplines. In these last countries, a coherent view of science teaching is not explicit. In terms of labwork, only in England and Denmark is there an assessment of students' labwork at the end of this compulsory schooling. In the other countries it seems that teachers can choose whether to carry out experimental activities with pupils, and teachers may not necessarily have appropriate equipment.

In the *upper secondary school*, there are gross differences in educational organisation. For example, in England and Wales students choose each subject discipline whereas in the other countries the students choose an organised curriculum with particular emphasis on science, literature, languages, etc. which we will refer to as a curriculum *route*. In some countries such as Denmark, Greece and France, there is an official curriculum which specifies a time duration for each subject. In others, such as Germany and England, some criteria for assessment or some compulsory topics for each subject are given by a national body. The duration of science teaching varies greatly. In spite of these differences, commonalties appear, in particular for the scientific routes: science is taught as separate subject disciplines like biology, chemistry, geology, physics; there is no integrated science teaching. Concerning labwork activities, working in small groups with experimental devices is very common in Denmark, England and France, whereas in Germany labwork is rare, depending upon individual teachers' motivations. In Spain, labwork is not very frequent and in Italy and Greece it is only done in specific schools.

At *university level*, in all countries, science teaching includes regular labwork.

There appear to be great differences between countries, at the lower secondary school level, in the organisation of science education and the place of labwork within it. The age when students choose a science route is rather different from one country to another. However at Upper secondary school, in scientific routes, the differences are smaller, the main one being that labwork is not practised currently in every country. It becomes a common practice at the University level in all countries.

[The corresponding work is presented in the *Working Paper 2*, *part 1*].

1 . 2 Teaching practice and students' activities in labwork

1 . 2 . 1 Rationale

At the outset of the project, it was agreed that teachers' views of science would have a potential influence upon their objectives for students' learning during labwork, and also upon the design of labwork tasks. It was also agreed that students' views of science would have a potential influence upon their actions during labwork, and their learning as a result of that labwork. These claims are taken into account in the tool of description of labwork called *'The map of variety of labwork'* (see chapter 1 of Part 3). It is the reason why some results concerning the epistemological aspects of labwork are necessary to introduce the conclusions stemming from the analysis of the existing and possible practices. The existing practices are presented mainly through the organisation of labwork and teachers' objectives , whilst possible objectives are presented from the 23 case-studies carried out for the project.

1 . 2 . 2 Students' and teachers' views of science: Epistemological aspects of labwork

Students' and teachers' ideas about science in areas relevant to teaching and learning during labwork, were investigated by survey.

Students' views

During labwork, students draw upon images of science to explain the purposes of empirical investigation, relationships between data and knowledge claims, and relationships between knowledge claims and experimental design, analysis and interpretation of data.

A closed-response written survey was developed building upon previous research and piloting questions before using them in the final survey.

Results show, generally speaking, that large numbers of both upper secondary and university students drew upon images of science when answering the probes that suggested a relatively sophisticated understanding of the role of theory and data in empirical investigation. With respect to the relationships between data and knowledge claims, for example, around 50% seemed to appreciate the implications of spread of data upon confidence in estimates made from that data. However, large numbers of students appeared to use a view that knowledge claims arise unproblematically from the logical analysis of observational data, or that conclusions can be made on the basis of data alone without reference to underlying theory. With respect to the relationships between knowledge claims (theory) and experimental design, analysis and interpretation of data, for example, around 50% of students selected responses which stated that theory is involved in designing data collection and analysing and concluding during investigations. With respect to the purposes of empirical investigation, a significant number of students in the sample (around 10% to 20%) appeared willing to make far-reaching decisions based on inconclusive data (e.g. closing a chemical plant down). Generally speaking there is little evidence of differences in the images of science drawn upon by physics, chemistry and biology students at the university level. However, in a number of cases more biology students appeared to hold data-focused views compared to physical science students. The differences in the frequencies of responses between upper secondary and university students were quite modest (around 10%). In some cases, however, up to 40% more university students selected responses indicating a view that data and theory are intimately linked during empirical work.

Students exhibited similar thinking in several case studies, suggesting that the findings of this survey might well be a good predictor of student actions during actual labwork.

It can be concluded from this work that students at the undergraduate and upper secondary level commonly draw upon three broad representations of empirical work in various contexts relevant to labwork learning. These are a *data-focused view* in which scientific knowledge claims are viewed as descriptions of actual events in the material world, a *radical relativist view* in which it is not thought possible to evaluate scientific knowledge claims in terms of data, and a *theory and data related view* in which knowledge claims, data and experimental methods are thought to be inter-related and interdependent. Although a case might be made for the validity of each of these views in some contexts, many students drew upon data focused views and radical relativist views inappropriately.

[The corresponding work is presented in the *Working Paper* 4].

Teachers' views

In parallel with the study of students' images of science an investigation on the images of science of teachers was carried out in two countries (Italy and France). The investigation was based on the recognition that the views of science held by teachers may influence their didactical activity and therefore the students' views. It was also recognised that traditions exist in each country, and that teachers' training, choice of objectives for science teaching, etc. do influence the images of science conveyed by teachers.

The Italian group therefore chose a set of ten questions from the database developed in the project and adapted them to the Italian context. Some of the questions were relevant also for France. This allowed a pilot study which produced an in depth critics of existing questions and propositions to improve them, providing the possibility to survey groups of teachers and make them ponder on their philosophical stance. The study showed the validity of seven of the ten questions and some first results were obtained concerning the place attributed to empirical data and theoretical considerations in building knowledge, in a general frame of what is science.

This survey is helpful to characterise which can be the share of teachers in forming students' images of science. The influence of the national specificity for Education has been stressed and should be taken into account. Implications are numerous for teachers' training where the didactical activity should be framed in an epistemological context strongly related with the disciplinary and historical aspects. Furthermore the connection with the contemporary research world should be encouraged in Secondary School teachers' training.

[The corresponding work is presented in the *Working Paper 5*].

1 . 2 . 3 Patterns of organisation for labwork in seven European countries

Both surveys and case studies have been used to illustrate the ways in which labwork is currently organised, the objectives currently addressed by teachers through labwork, and additional ways in which labwork might potentially be used to enhance students' learning.

The organisation of labwork: existing practices

A survey was used to investigate the main ways in which labwork is currently organised by more than 400 teachers from the different countries at upper secondary school and university.

The main results show commonalties in the ways in which labwork is organised at both the undergraduate and the secondary school level. Most of the time, students are in small groups with labwork activities to carry out according to the teacher's instructions. Assessment is usually performed using the student's written report of the labwork activity, most marks being given for 'thorough interpretation of results'. By contrast, 'effective groups work' is not taken into account. Computers are normally used only for data processing. Open-ended labwork is commonly much less frequent than more guided approaches. However, open-ended labwork is used in some countries, if less frequently than other approaches. The use of CD-ROMs or the Internet is very rare.

The results also show differences between the university and secondary school levels. The link between lectures and labwork is strong at secondary school, whereas at least in France, England, and Germany, the link is much weaker at university. This finding can be easily attributed to the different organisation of universities and upper secondary schools, and the fact that at secondary school, in a given discipline, one teacher is responsible for all aspects of teaching. In addition, there are no strong differences between countries and between subject disciplines. There is no link between whether 'typical' labwork is performed by a teacher, and whether that teacher uses demonstrations in teaching.

In conclusion, in spite of the variety of educational organisations, labwork practice is not so different from one country to another or from one discipline to another. There appears to be an international and implicit paradigm of what a labwork is: current practice is deeply anchored. These findings are important in guiding any attempts to improve labwork.

[The corresponding work is presented in the *Working Paper 2, part 2*].

The organisation of labwork: a variety of possibilities

This similarity of organisational practices for labwork at a rather general level of description should not hide the variety of possible practices for labwork. Indeed, the 23 case studies have illustrated a variety of possibilities. Two main organisational frameworks were apparent amongst the 23 case studies. The first of these involves laboratory activities involving the application of specific teaching strategies including the use of new technologies, but where each labwork activity was planned discretely.

The second organisational framework involves the planning of a series of lectures and labwork activities in a particular sequence designed to integrate labwork activities and the communication of conceptual/theoretical information. In some cases a semester long teaching sequence was supported by specific labwork activities. In other cases, computer simulated models and hands-on experiments were integrated in teaching sequences and labwork sessions were developed which integrated hands-on activities and computer modelling systems.

The 23 case studies illustrate the diverse organisational structures for labwork in the curriculum that support science learning. In addition to the possible objectives of typical labwork which could be studied in depth, the potential objectives of sessions including new technologies, open-ended labwork , etc. have been disclosed.

[The corresponding work is presented in the *Working Paper 7*].

1 . 2 . 4 Learning objectives for labwork

Three complementary approaches were used to characterise the complexity of the situations in which labwork is used, and the purposes for which it is used. The first of these was an attempt to conceptualise from a research perspective the intended learning objectives of labwork and how these relate to the design of labwork tasks, and the various actions that students take during labwork and how these relate to students' learning (*'Map of the variety of labwork'*). The second involves characterising teachers' objectives for labwork. The third was designed in order to characterise the diverse aims and objectives for labwork reflected in the 23 case studies.

A map of the variety of labwork

The purpose of the *'Map of the variety of labwork'* was to conceptualise and allow for description from the outset of the research possible objectives for labwork and their relationship with student actions during labwork and student learning during and after labwork. In particular, it focuses upon what students are intended to do during labwork with objects and ideas, and what they actually do. The dimensions of the map are as follows:

A - Intended learning outcome: gives a series of possible intended objectives.
B1 Design features of task proposed to students: two types of features are defined, the students' intended activity with objects and with ideas such as using, making or observing object, a laboratory procedure, etc. or exploring relationships, determining values, testing, etc.
B2 The details of the context such as the duration, people with whom student interacts, etc.

The *'map of the variety of labwork'* is an original tool for describing labwork, available to teachers as well as to policy makers and researchers, allowing them to evaluate the effectiveness of labwork. It constituted a common basis for communication about labwork within the consortium.

[The corresponding work is presented in the *Working Paper 1*].

Analysis of labwork sheets using the 'Map of the variety of labwork'
The map was useful in addressing the extent to which and the ways in which labwork differs between levels, disciplines and countries within Europe. 175 labwork sheets from several European countries were therefore selected as representative of the labwork typically done in each country, and coded by each research group in terms of the categories of the *'Map of the variety of labwork'*. These analyses were collected and analysed systematically. This analysis, although based upon a rather small number of labwork sheets, illustrates common tendencies in labwork and allows for the proposition of a method for comparing labwork activity between countries, disciplines and levels on a large scale.

This description of common labwork activities using the *'Map of the variety of labwork'* shows very strong tendencies. The duration, the people with whom students interact, the teachers' definition of the question to be addressed and the equipment used are very much the same according to most of the labwork sheets. The students collect almost all information from 'the real world' inside the laboratory. Little information is gathered from computers, CD-ROMs, videos or 'the real world' outside the laboratory. In effect, the students' investigations are carried out to address the laboratory context exclusively. Labwork is not used as an opportunity to study the everyday world directly or to study the industrial world.

These results are striking not only from the point of view of what the students have to do but also from what they do not have to do. At secondary school, the students have to use standard procedures, to measure, and to make direct reports of observations. They do not have to present, display or make an object. They do not have to explore relationships between objects, to test predictions, to choose between two (or more) explanations. Even at university, it appears rare that students are asked to test predictions or to account for observations in terms of a law or a theory.

In conclusion, the similarity both between disciplines and countries concerning usual labwork activities is more than it might be expected from the differences in the educational systems of each country. Usually, labwork involves a few similar types of activities. Other activities such as "to do account for observations in terms of law or theory" or "to choose between explanations" are rarely involved in labwork. This finding raises the possibility of designing labwork in new ways to meet a wider variety of objectives.

[The corresponding work is presented in *Working Paper 3*].

The survey 'Teachers' objectives for labwork'

A survey was developed to investigate *'Teachers' objectives for labwork'* in science teaching at upper secondary and first year university level in different European countries (Denmark, France, Germany, Great Britain, Greece and Italy), and different science subjects (biology, chemistry and physics).

The most important finding is that teachers identify three broad objectives as most important for labwork with nearly equal average ranking on a scale from 0 to 5 (highest rank): (A) for the student to link theory to practice (average rank 4.1), (B) for the student to learn experimental skills (3.6) and (C) for the student to get to know the methods of scientific thinking (3.7). More than 40% of the teachers ranked the category A (to link theory to practice) as the most important one. The categories B and C got both the most weight for the second rank, but C (for the student get to know the methods of scientific thinking) was given the highest rank more often than B. Differences between country samples show only minor differences, e.g. in the French sample "to develop scientific thinking" shows the highest average rank value. There are some significant differences between the answers of the different levels: The objective "to learn experimental skills" seems to be more important for labwork at university than for labwork at secondary school. "To foster motivation, personal development and social competence" by doing labwork were ranked higher at school level than at university level. With respect to different subjects, the category C ("to get to know the methods of scientific thinking") is ranked higher by the Biology teachers than by others. "To link theory to practice" through labwork is ranked highest by physics teachers.
The study revealed also some subcategories of aims which seem to be important to teachers. For (A) "to link theory to practice" important subcategories seem to be (A4) "understanding of theory through practice", (A1) "to improve understanding of theory", and (A10) "to solve problems which arise from an experiment". Less important seem to be (A9) "to introduce notation and technical terms" and (A3) "to make phenomena occur".

Overall the results from this survey are important in order to know what teachers expect from labwork and to guide future research in the domain. The recommendations as outcomes of the project will take into account the expectations voiced by teachers. Moreover the questionnaire itself constitutes an outcome of the work, as a research tool.

More details of methodology and results can be found in *Working Paper 6*

Case studies: The variety of objectives for labwork exhibited

The analysis of the 23 case-studies allowed for the formulation of a model of labwork objectives and their respective links. Although any piece of labwork inevitably requires students to draw upon a complex network of knowledge, it was possible to identify an explicit view of the most fundamental learning for each case study. The following inter-related categories of learning objectives might therefore be addressed in labwork: conceptual understanding, an understanding of laboratory procedures, or epistemological understanding.

Such a categorisation recognises that any piece of labwork may well address several categories of learning objectives. It also recognises that any one learning objective may be addressed with different emphasis depending upon the context. For example, data processing can be taught discretely as a laboratory procedure, or alternatively the underlying epistemological assumptions inherent in data processing can be addressed. The presentation of data processing as a routine procedure is widespread in textbooks and laboratory manuals. If underlying epistemological assumptions are to be addressed during labwork, the survey on '*Students' images of science*' may well be valuable in identifying aspects of students' epistemological understanding that might be addressed.

[The corresponding work is presented in the *Working Paper 7*].

1 . 3 The effectiveness of labwork

The three main objectives for labwork identified by teachers in the survey *'Teachers' objectives for labwork'* were 'to link theory and practice', 'to learn experimental skills' and 'to get to know the methods of scientific thinking'. In this section, the effectiveness of different organisational strategies for labwork is evaluated in terms of the activities actually performed by students during labwork ('effectiveness 1'), and in terms of students' learning as a result of labwork ('effectiveness 2'). In the case of 'effectiveness 1', the success of different organisational strategies for labwork is addressed in terms of their ability in getting students 'to link theory and practice', 'to learn experimental skills' and 'to get to know the methods of scientific thinking' during labwork activities. In the case of 'effectiveness 2' , the success of different organisational strategies for labwork is addressed in terms of students' understanding of concepts/models/theories, experimental skills and methods of scientific thinking as assessed after teaching.

1 . 3 . 1 The effectiveness of labwork determined by comparing students' actual activities with intended activities ("effectiveness 1")

'Effectiveness 1' addresses the extent to which specific ways of organising labwork result in students carrying out the activities intended. No attempt is made to analyse more deeply the outcomes of those activities in terms of student learning. Examples of the activities that students are intended to undertake include talking about scientific concepts (e.g. formulating explanations, making predictions), designing experiments and discussing the confidence that can be attributed to data.

The effectiveness of different organisational strategies for labwork in helping students "to link theory to practice"

Most of the results summarised in this section were gained with a new method of data analysis, termed *'category-based analysis of video tapes from labwork'* (CBAV). The method was used to compare organisational strategies for labwork (such as working with written guidance materials or making measurements), and categories addressing links made by students between theoretical knowledge (*'theory'*) and actual activities involving real objects (*'practice'*). Organisational strategies for labwork will be referred to as 'labwork contexts'. Examples of activities involving students in making links between theory and practice include talking about scientific concepts or talking about relations between scientific concepts and real objects.

Data about the labwork context '*doing measurements*' indicate two things. Firstly, making measurements is typically very time consuming, taking around 20% to 50% of the time available. Secondly, students typically talk about scientific concepts for little of this time (typically around 10%). In effect, making measurements does not contribute a lot to getting students link theory to practice during labwork, if taken in isolation. In addition, during most of the labwork analysed little time is devoted to performing calculations and using mathematical knowledge. Students seem to deal mainly with what they are told to do, either by the support materials for the activity (the 'labguide') or by the tutor, and do not spontaneously make links between theory and practice. Strategies for overcoming this include reducing the time spent in making measurements or combining the process of measuring with tasks like making predictions or performing rough theoretical calculations. These additional tasks could be built into labguides or made by the tutor. In cases where these strategies were used, students spend more time talking about scientific concepts (up to 45% of the time spent with the tutor, and up to about 15% of the time spent with a new labguide).

The use of computers in making measurements and assisting with data analysis does not inevitably result in students making more links between theory and practice, though in some cases this was apparent. Although students using computer tools for data handling and processing did not result in students making more links between theory and practice, the use of model building software was successful in making students make links between theory and practice, and in some cases students spent up to 68% of their time making such links.

In addition to the above findings gained using the CBAV method, other case studies addressed students' abilities to make links between the behaviour of real objects and phenomena and scientific theory. Teaching was successful in allowing students to make such links if this objective was built into the design of the teaching.

The design of labwork sheets, the choice of resources and the training of tutors are crucial for improving the effectiveness of labwork.

Results come from the category based analysis of videotapes from labwork [*Working Paper 9*] and from single case studies [*Working Papers 7 and 8*].

Experimental procedures, skills and know-how

During labwork students manage to 'make things work', often without understanding the rationale that lies behind what they do. Some conditions seem necessary to obtain 'effectiveness 1' regarding skills and know-how. For instance the case study FD1 addressed how software can be used for data gathering, data processing and differential equation solving. It appeared that a specific structure of the labwork session is necessary to avoid an algorithmic and meaningless application by students of instructions as to how to use the computer. In other words, the study provide hints concerning the necessary know-how to be taught to insure some autonomy by students in the way in which they can use the computer.

Another example is that, not only researchers, but also teachers know that procedures underlying the actions to be carried out by students (and generally carried out correctly) are not understood. The reasons to choose and to follow such and such process, are not made conscious to students during typical labwork. Some of the case-studies addressed this problem of understanding and consciousness of procedures and know-how. Several means to improve guidance from teachers and labsheets from this point of view, are suggested.

The effectiveness of labwork aiming to get students 'to get to know the methods of scientific thinking'

Two case-studies attempt to help students to carry out approaches in their own labwork that are close to the approaches used by physicists, and to adopt these approaches with an explicit understanding of why they are used in physics. To obtain this understanding, the approaches used by physicists are taught directly, the lecture being based on a labwork session used to exemplify the procedures in use. In order to help students to distinguish different kinds of approaches, each of them is characterised by a given type of model: theoretical, behavioural, mathematical, simulated, etc. In this teaching, which was spread over two full years (the first two years of university), students have the opportunity to identify and carry out different types of approaches, as described and taught during the first term, through guided labwork. They also are given the opportunity to do the same during open-ended projects. The outcomes of the projects which in effect constitute an assessment of what has been learned, are reported in the following section.

1 . 3 . 2 The effectiveness of labwork determined by comparing students' actual learning with the learning objectives of the activity ("effectiveness 2")

The effectiveness of labwork aiming to get students "to learn a concept/model/theory"

Many of the case studies showed that although students did indeed learn something about particular concepts/models/theories during labwork, there were factors limiting this learning. There is little evidence that individual labwork activities in themselves change students' underlying knowledge structures (although they may learn a lot about experimental methods and procedures). However, carefully designed sequences in which labwork and other teaching methods are integrated can lead to changes in students' conceptual understanding

In order to improve the effectiveness of labwork in developing students' conceptual understanding it is necessary to identify content-centred objectives for the labwork, possibly rejecting some other possible objectives for the labwork.

The effectiveness of labwork aiming to get students "to learn experimental skills"

In three case studies, students' understanding of measurement errors and the uncertainties associated with measured values was analysed. In each case study, problems were identified in teaching students about the uncertainties associated with measurements and the relationships between measured data and theory. In two of the case studies, the poor performance of students was attributable to some extent to the fact that the teaching approach did not place sufficient emphasis upon the underlying epistemological dimension of data analysis. In another case study, a teaching strategy was investigated that had some success in teaching students about uncertainties in measurement, though after teaching many students still exhibited a partial understanding.

For the above reasons it is therefore recommended that science curricula address explicitly the basis for standard data processing techniques with students at an early stage, if students are expected to understand the rationale behind such techniques.

More specific results come from particular case studies [*Working paper 7 and 8*] and from the survey *'Students' images of science'* [*Working paper 4*].

Effectiveness of labwork aiming to get students "to get to know the methods of scientific thinking"

It is difficult to assess students' abilities at performing tasks such as designing empirical investigations and analysing data after labwork has taken place and in isolation from a real task that has to be undertaken. However, there was some evidence from the case studies that students learnt a good deal about the procedures typically used during empirical investigations. It is likely that students would be able to draw upon at least some of this learning in performing different labwork tasks in the future.

1 . 3 . 3 The effectiveness of selected types of labwork

New technology integrated into labwork

The effects of new technology were analysed in 9 case studies. In these case studies, new technology is integrated into labwork in a variety of ways. *Computers* are used for data collection (MBL), for data analysis and the graphical representation of data, for model building, to simulate a physical model, to demonstrate an interactive microscopic model for electrical polarisation, as well as for combinations of these uses. *Video films* are produced and used to demonstrate microscopic models (e.g. for heat or for sound), as well as to illustrate connections between real world phenomena and laboratory experiments.

Results from empirical research show many positive effects attributable to the integration of new technologies in labwork, but also some negative effects and open problems. In most of the case studies, students were able to learn to use the software with ease. However, in one case study some problems were identified associated with students learning the syntax required by specific software. In addition, although students were often able to follow algorithms given by teachers for using the software, in some cases this approach left students with little understanding of the underlying rationale for the use of the software with the result that they had limited autonomy in using the software for themselves.

The capability of the computer screen to present real-time graphical information was important in allowing students to connect the real phenomena in question their graphical representation. Using simulations of microscopic models to explain phenomena during labwork - either as computer simulations or as video films - was successful in promoting conceptual understanding. The use of model building software stimulated students to talk more about the conceptual background of a specific labwork situation than most other forms of labwork. But students do not necessarily make spontaneous links between theory and objects and events in the real world at the same time. Teaching approaches which combine labwork with interactive computer simulations or microscopic models and 'thinking tasks' for students (e.g. prediction and explanation) can contribute to the development of conceptual understanding . Students' collaborative discourse is enhanced if they have common reference points such as shared experimental equipment and shared labwork sheets.

Open-ended labwork and projects

The effectiveness of open ended laboratory work in science education has been investigated in five case studies. It appears from these case studies that open ended labwork addresses the development of students' understanding of scientific procedures in a more focused way than 'typical' labwork, without neglecting conceptual learning.

The importance of clarity in explaining the target scientific procedures to students is illustrated in a case-study. Project work in biology was successful in achieving the aim of preparing students for more ambitious open-ended project work later in the university course, though the projects were less successful in engendering a sound conceptual understanding amongst the students. The main reason for this appeared to be that tutors gave students conflicting messages between on the one hand the need to have a sound conceptual understanding to complete the project, and on the other hand the fact that projects that are technically unsuccessful can nonetheless help students to understand how to plan open-ended empirical enquiries.

Results from yet another case study suggest that the epistemological framework taught during three semesters was effective in helping students to link various phases of open ended projects. This study suggests that a project can be especially useful in making students aware of the epistemological basis of scientific activity.

Another case study focused on field work carried out by geology students. Field work turned out to be very valuable for the students in making links between previously detached pieces of knowledge taught in various different courses. However, the students used their knowledge in a rather fragmentary "local" way in the field and tended to design their investigations to "see what happens" rather than to establish strong links between field observations and geological theories. The field environment proved unique in helping students to learn things like navigation which it is virtually impossible to re-enact in the laboratory.

The alternative of textbooks

In some situations it may be necessary to use reports of experiments in textbooks in place of labwork with real apparatus. Findings from a study show how many textbooks convey an image of science which tends to sustain rote learning rather than illustrating the role of experimental activities in constructing scientific knowledge. It also tends to discourage personal involvement and a speculative attitude on the part of students. This case study provides ideas which might usefully inform the presentation of experiments in textbooks.

The use of secondary data

The use of secondary data was analysed in one case study . Data from both surveys and interviews suggests that many students did not hold clear understandings about how the data were collected, errors that were associated with it and the significance of values in terms of scientific models. However, findings from this case study might usefully be used to overcome these problems in the design of data handling activities.

1 . 4 New tools for evaluation and research

During the whole project, six new tools for use in future research and for use in the evaluation of teaching were developed:

- A conceptual framework for analysing learning objectives and students' actions during labwork (the *'Map of the variety of labwork; Working Paper 1*)
- A survey instrument to identify the structure and organisation of labwork teaching at the upper secondary and university level (the survey of *'Current labwork practices'; Working Paper 2)*
- A survey instrument and associated research hypotheses to investigate the epistemological understanding likely to be drawn upon by students during labwork (the survey of *'Students' images of science'; Working Paper 4*)
- A survey instrument to investigate the images of science drawn upon by teachers during labwork (the survey of *'Teachers' images of science'; Working Paper 5*)
- A survey instrument to investigate the learning objectives attributed to labwork by teachers (the survey of *'Teachers' objectives for labwork; Working Paper 6*)
- A method for the analysis of video tapes from labwork ("category-based analysis of videotapes; CBAV"; *Working Paper 9*)

These tools may be useful to researchers, teachers and policy makers.

Conclusion

From the common work, aimed at eliciting what exists in Europe at the present time and what can be achieved, new means for effectiveness and new observation tools are now available to teachers. The work leads to documented policy implications which are the subject of the next chapter.

Chapter 2

APPLICATIONS TO SCIENCE EDUCATION

AND POLICY IMPLICATIONS

The preceding results give rise to a number of recommendations about future directions and possibilities for the use of labwork in science education. Although these recommendations arise from the research, they can only be used and applied in terms of a clear policy framework The application and implementation of findings does not arise directly from the research itself. It is an inevitable consequence of strong national traditions in education and in science education that the policy implications from research will be different in different countries, as was stressed by the survey *'Current labwork practices'* and to a lesser extent by the survey *Teachers images of science.* Indeed, discussions and exchanges inside the consortium concerning these two surveys and other work highlighted some differences of opinion. This is illustrated later in this chapter, with respect to the different emphasis placed upon measurement in the scientific process, and also the teaching of measurement.

In this chapter we will present some possible applications of the common work of the consortium of the project under four principal headings:

Possible objectives
Labwork could address a broader range of learning objectives than the range currently addressed. It has been possible to identify several possible objectives that are presently under-exploited. The respective roles that can be attributed to these objectives are discussed later in this chapter.

Targeted labwork
Labwork could be better designed to address clearly defined learning objectives. Fewer objectives for each labwork session and a more coherent overall organisation of labwork ought to lead to improvements in student learning.

Effectiveness and evaluation
This section focuses upon how targeted labwork might be designed to be more effective. It also raises the issue of evaluating the effectiveness of labwork.

Teacher education
Teachers have a critical role in determining the effectiveness of labwork, as they are generally responsible for the design of labwork, for writing labwork sheets and for teaching during labwork sessions. This section addresses implications from the project for teacher education.

The role of new technologies in labwork, and particularly computers, is not treated on its own. Rather, what such technologies can add, change and improve is addressed in each section.

2 . 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, students could learn more from labwork.

A preliminary model of learning objectives for labwork has been developed during the project, drawing upon the surveys and case studies. This will no doubt be refined as further research is conducted. However, we are in a position to state that many potential objectives for labwork are not currently addressed. In particular, labwork rarely addresses epistemological objectives. In the case studies it was apparent that students do not learn about underlying epistemological issues in labwork if these are not addressed explicitly, and that even if such issues are addressed directly not all students will develop an appropriate understanding.

2 . 1 . 1 The place of conceptual knowledge amongst the learning objectives for labwork

Conceptual learning is both an explicit and implicit learning objective for teachers during labwork. In the survey *'Teachers' objectives for labwork'*, teachers commonly identified making links between theory and practice as learning aims for students. In addition, the analysis of labwork sheets shows that conceptual learning has a prominent place in labwork. If students were required to work on the labwork sheets before the corresponding labwork sessions, this would improve the effectiveness of the labwork in promoting conceptual learning. However, students tend to be able to perform reasonably well during labwork sessions without devoting this time to underlying theoretical considerations. 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 on considering the underlying theoretical background of labwork tasks is very small, suggesting a need for improvement.

A first idea is to identify this objective for labwork clearly.

For those who support the idea of introducing 'theory' before 'practice', specific ways have to be found to get students to address theory during labwork. Questions in the labwork sheet and questions posed by the tutor should be really focused upon the underlying theory of labwork activities. One of the most effective ways of focusing students on the relationship between theory and practice is to address issues of modelling directly. By definition, students have to address links between theory and practice in activities such as constructing a model, using a model in particular situations, comparing models and searching for the value of a parameter to fit a model. Computers can be of great help in such cases, as can videos designed to focus on the theoretical underpinnings of labwork.

The limitations of a discovery view of learning have been known for many years, and very different justifications have to be found for the idea of introducing ‘practice’ before ‘theory’. The context of open-ended project work 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’. Although students may attain a deep conceptual understanding through project work, this understanding may be restricted to a limited number of topics that are very similar to the project itself. Another possibility is to ask students to make predictions more often in order to make them focus more strongly on theoretical aspects of the labwork. Students might be asked to make predictions about the behaviour of events, or alternatively to make predictions about orders of magnitude etc. before actually making measurements.

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 can not be learned effectively through labwork if the labwork activity is not designed towards this aim. In effect, although labwork is not an unique solution to teaching the concepts and laws of science, more about the concepts and laws of science could be taught through labwork than is typically done.

2 . 1 . 2 The place of procedures and experimental design among the objectives of labwork

Any piece of labwork requires students to undertake procedures. Most of these are theory-laden to a greater or lesser extent. The decision as to whether to teach about the relationship between theory and procedure is open to question, though teachers do tend to identify the teaching of procedures as an important goal for labwork, particularly with more advanced students who may soon be entering professional work.

However, just as it cannot be expected that students learn concepts that are not addressed explicitly in teaching, 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. Experimental design is a particularly effective context for teaching epistemological knowledge, as will be described below. If students are not taught procedures, then their autonomy for designing experiments will inevitably be reduced.

Amongst all the procedures used in labwork, special prominence must be given to computing skills. It is important that the computing skills required during labwork are addressed directly in teaching. If such skills are not addressed, students will have to rely upon algorithms that are not underpinned by more principled understanding, with the risk that students’ autonomy during labwork will be reduced.

When teachers design labwork they do so with an implicit understanding of the procedures to be used. By and large, students do not appear to recognise which procedures are being used. A major objective for labwork identified by teachers is to teach about experimental design, one of the most creative processes in science. However, there are often good reasons why students are not involved in the design of labwork. In such cases, it may be useful for discussions to focus upon the characteristics of the apparatus and instruments in use, drawing upon either contemporary uses in the teaching laboratory or historical examples. In this way, factors like the control of relevant variables, the elimination of unfavourable effects, orders of magnitude, uncertainties and procedures of data collection can be addressed even though students have not designed the experiment for themselves.

2 . 1 . 3 The place of measurement collection among the objectives for labwork

During labwork there is a constant interplay between the collection of data (observations, measurements etc.) and theory. The question is how much of this should be taught explicitly in each scientific discipline at different academic levels.

From the surveys, it seems that at both upper secondary and university level students are involved in making measurements during much physics labwork, and also during chemistry and biology labwork in which physical quantities are pertinent. During the LSE project, the place of measurement during labwork was increasingly questioned. One the one hand, the process of measuring is very common in scientific practice, though on the other hand the measurements made by students tend to take a lot of time and can easily be rated as 'good' and 'bad' on the basis of individual students' care and ability. Also, students do not typically make links between 'theory' and 'practice' while they are making measurements. It therefore seems appropriate to make careful judgements about the overall duration of this sort of activity amongst other possible labwork activities. 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.

In addition, the process of measuring may require students to make decisions about what to measure and what measuring device to use, and these decisions will be based upon some understanding of underlying aims and principles for measurement. In effect, student autonomy can be increased.

- The worst situation is that of time spent making many measurements without a clear understanding of the rationale for measuring and reasons for the choice of measuring apparatus.
- The best situation is not easy to design or carry out, though it might involve project work in which students develop a rationale for measurement, design a strategy for data collection and analysis, and consider orders of magnitude and uncertainties in their data before drawing conclusions in line with the aims of the activity.

Obviously, computers and sensors can play an important role in saving time. Again, the significance of the measurement must be addressed directly in teaching and not hidden behind routines.

The data handled in labwork inn the disciplines of biology and geology are often qualitative rather than quantitative. Teachers therefore need particular skills in introducing students to the procedures and routines associated with collecting and handling qualitative data.

2 . 1 . 4 The place of data processing, the development of conclusions and the corresponding mathematical tools among the objectives for labwork

As stated before, several objectives can be achieved from measurement and observation during labwork. These include data processing and the development of conclusions, both of which may require the use of mathematical tools. All theses objectives 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 case studies and surveys suggest diverse reasons as to why one or the other approach might be adopted. A certain reluctance on the part of students to draw conclusions at the end of a labwork session was noted. Attaching an important epistemological issue to the phase of labwork in which conclusions are drawn is a possible way to promote students' interest.

Several examples of the successful teaching of mathematical tools can be identified from amongst the case studies. Statistical analysis, the meaning of graphical representations etc. can be identified as objectives for labwork sessions, taught and learned. The use of computers and pocket calculators with specific software appeared particularly effective in some case studies.

2 . 1 . 5 The place of (meta-) epistemological knowledge among the objectives of labwork

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.

Work from this project gives rise to original ideas about how opportunities in labwork can be maximised 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 question of what aspects of epistemology might be taught to students. In addressing this question it would be useful to exemplify more precisely the methods that are used in science, going beyond superficial definitions of 'the methods of physics, chemistry and biology' towards views of the activities of academic research scientists, engineers and industrial scientists. Such views would help to inform decisions about the types of epistemological understanding that students require for labwork. In addition, 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 . 2 Each labwork session should be reasonably ambitious and TARGETED, the strategy being a clear orientation towards certain objectives.

***A long term coherent structure of labwork is necessary*.**

2 . 2 . 1 'Targeted' sessions of labwork

It has been shown that the labwork sessions throughout Europe are complex, putting into operation ingenious experiments and attempting to develop numerous useful skills. It has also been shown through careful observation that students' learning from these carefully designed situations is rather limited. 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 process of adapting labwork towards a narrower range of more precisely defined objectives is referred to as producing '*targeted* ' labwork sessions.

2 . 2 . 3 Sequences of labwork with an overall coherence, complementary labwork sessions and enlargement of the types of labwork

If each labwork session has a limited number of objectives, it becomes necessary to organise students' overall programme of labwork activities within a coherent long-term programme, implying the use of complementary activities to cover a wider range of objectives.

The implication of this is that students should no longer be required to undertake a series of labwork sessions in any order, each session aiming at numerous objectives. Furthermore, each series of labwork sessions should include labwork aiming at different types of objectives. For example, conceptual reflection might precede epistemological reflection on a given task, or procedures might be studied through their use in different theoretical contexts, or guided labwork might be used in preparation for more open-ended project work.

This assumes that the types of labwork undertaken by students should be varied. For example, selected part of the whole experimental process (see for instance what is called 'dry practicals' in Great Britain), 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 enhancing the possibility of students acting autonomously. If this is to happen a generous time allocation has to be given to project work, possibly several weeks. This raises the issue of whether project work is possible within a curriculum crowded by content, and the relative emphasis within the overall curriculum placed upon content areas compared to outcomes such as student autonomy and creativity, and student understanding of experimental procedures and approaches.

2 . 3 Two types of effectiveness should intervene in labwork. Linked to effectiveness, specific evaluation has to be implemented

2 . 3 . 1 Selecting objectives means aiming at specific learning as well as specific activities during labwork

In the previous section it was stated that a variety of different kinds of knowledge can be learned through labwork, and several learning objectives can be addressed. Furthermore, a major outcome of the LSE project is 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. 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.

It appears necessary to plan experimental activities to engender both types of effectiveness. A number of tools developed in this project are available to help teachers in this task, such as the *'Map of variety of labwork'* [Working paper 1] which gives the multiple dimensions of description that might be taken into account in labwork, and the new types of labwork sheets that are suggested in the case studies.

2 . 3 . 2 Specific evaluation has to be developed

Tools for the assessment of **learning objectives** [effectiveness 1] exist. However, if learning objectives are more carefully selected and defined, these tools ought to be refined. For instance, few written questions addressing the acquisition of knowledge about procedures by students are currently available. Some suggestions about the wording of such questions can be found in case studies from the project. Specific research involving collaborative work between researchers and teachers should be undertaken to produce new tools. The same can be said for epistemological knowledge. Selected tasks addressing specific aspects of epistemological understanding could be used to make assessments of students' understanding. Some first ideas can be found in the survey *'Students' images of science'*.

It must be emphasised here that there is a correspondence between the *objectives* of labwork and the *assessment* of labwork, rather than a direct correspondence between the assessment of labwork and the labwork task. In fact it has been emphasised that a given task can be directed towards different learning objectives. For instance, this is the case for measurement processing which is often used to teach about procedures, but is used more rarely for getting students to link theory and practice, and might well be used to teach about epistemology.

Tools for the assessment of **activity and understanding during labwork** are less well developed at present. In the case studies that have been carried out some examples of tools can be found, or at least examples from a research design might be adapted to a teaching context. In this respect, the role of teachers in charge of labwork is crucial. The implications of this for teacher education have to be addressed (see below). Similarly, a very different view of labwork sheets must be developed to achieve this sort of effectiveness during labwork.

2 . 4 A condition for improved effectiveness is a different focus for teacher' education and a deep transformation of resources, labwork sheets and the types of guidance available to students during labwork

2 . 4 . 1 The teachers' tasks during to labwork

The role of the teacher in promoting student learning during labwork has only been addressed in a few case studies. In some cases, teachers appeared relatively poor in articulating learning objectives for labwork activities. In other cases, however, the critical role of tutors in achieving discussion of scientific concepts during labwork was apparent. In many cases, the critical role of teachers in ensuring that labwork is effective was emphasised.

The role of teachers is clearly critical at different phases in labwork. For instance:

- When developing labwork, groups of teachers should work in collaboration to identify learning objectives, possibly consulting literature and/or the Internet;
- During this phase of development, teachers should not be aiming to fix every detail, procedure, and piece of apparatus to produce a ‘perfect’ experiment. Rather, they should abandon some possible learning objectives to promote others identified as being particularly important;
- This means that lectures have to be done at a level and with objectives consistent with labwork;
- 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 planned previously;
- After labwork, teachers have to organise specific assessment of students’ learning and to address different potential problems. These include the students’ expectation of an unique correct answer, value or model, as opposed to the possibility of several different solutions being proposed during the labwork activity.

2 . 4 . 2 Development in teacher education necessary to improve the effectiveness of labwork

The preceding description of the multiple tasks of teachers suggest that the teachers' role in labwork is not an easy one. It requires specific input during initial and in service training. The following methods can be envisaged:

- Involvement in action research seems a motivating and efficient way of educating teachers. It involves a close collaboration between teachers and researchers that is useful for both. It promotes a constant interplay between practice and reflection upon that practice.
- During initial training, it is powerful to involve future teachers in 'targeted' labwork, and then to help them make constructive criticisms and suggestions for improvement.
- Teachers could be taught about possible strategies for labwork, followed by opportunities for personal involvement in the use of various strategies.
- The epistemological dimension of labwork activities must be made clear to teachers. Innovative ways to promote epistemological knowledge among students from labwork have to be developed.
- Finally some studies on the ways that professional science is reflected to students during labwork are necessary. Occasional contacts with research and/or industry are envisaged in some countries.

Conclusion : Autonomy and motivation

The general objectives of promoting student autonomy and motivation have not been addressed directly in this project. However, our studies and the subsequent recommendations suggest some possible ways forward. For instance, 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.

Motivation to study science is currently identified as an objective for the education of young people. Our research suggests a likely link between student autonomy during labwork and student motivation. Both concepts are present in our future research plans.

Chapter 3

IDENTIFIED NEED FOR FUTURE EUROPEAN RESEARCH

As a result of 27 months of research, several directions of research to be continued have been identified. They are presented below under four themes. The first involves a direct continuation of the work, the others, though stemming from the existing work, require new hypotheses and methods.

3 . 1 Further knowledge concerning the effectiveness of labwork

3 . 1 . 1 The relationships between Effectiveness 1 and Effectiveness 2

We have emphasised that labwork has to focus upon carefully defined intellectual and practical activities and learning objectives. The links between what can be learned from what is actually done have not been completely elicited. This could be a fruitful direction for research. The method could be the longitudinal observation of students.

3 . 1 . 2 Assessment of what is done during labwork (effectiveness 1)

Similarly, practices have to be designed to assess what students do and think during labwork. Some research methods have been implemented with this aim in mind. They should now be developed to give rise to teaching practices.

3 . 1 . 3 New technologies and Internet, demonstrations, long term sequences

Among the possibilities for labwork organisation, some have to be studied further. For instance, several case-studies in physics address the use of software during labwork, with different functions (modelling, data processing, automatic measurement, etc.). More has to be done in other areas. Finding out information from the Internet and using it has not yet been studied. Few long term organisations of labwork have been studied and the potential of demonstrations are not yet known in depth.

3 . 1 . 4 Motivation

The present lack of motivation amongst students to study some domains of science has hardly been addressed. New concepts, coming from sociology as well as cognitive psychology have to be found to explain this phenomenon.

3 . 2 Knowledge necessary to convey an appropriate image of science

3 . 2 . 1 Teachers' image of science

A preliminary research tool has been developed. The study should go on to determine the main parameters influencing teachers' images of science.

3 . 2 . 2 Common epistemology and experimental approaches in three disciplines

It seems that teachers in the disciplines of physics, chemistry and biology in each country articulate a wish to teach an 'experimental approach' . A cross discipline study at different levels of teaching seems necessary.

3 . 2 . 3 The development of images of science in the long term for future scientists and non-science professionals alike

The final aim concerns results about the images of science held by students in the long-term and especially of the public use of scientific results. Longitudinal studies in collaboration with sociologists seem possible and necessary now.

3 . 3 Knowledge necessary to promote an authentic social education

3 . 3 . 1 Organisation and interactions

Through 23 case-studies some specific methods of organising labwork could be studied. More must be done to understand the impact of organisational structures on the students' ability to work in groups. The basis should be new studies of the social interactions that take place during labwork sessions A lot is known about interactions between students and teachers and students and their peers, though this has not been done in the context of labwork and field courses.

3 . 3 . 2 Autonomy and guidance

Promoting student autonomy appears as a general aim of labwork. The concept started to be refined through the studies in the project. These allow for the definition of different levels of autonomy: during projects, to design experiments, to judge the results, to draw conclusions, etc. During ‘typical’ sessions, to construct a personal meaning of the work, to make choices and decisions, particularly understanding whether several models/values are relevant or not.

The different levels of autonomy and guidance have to be studied amongst students at different ages in order to determine when and how they are most effective in terms of the definitions of labwork effectiveness.

3 . 3 . 3 Social aspects of the image of science for future scientists and non future scientists

The desire to know more about the impact of science education upon students who will not go on to work in science has been expressed. It concerns the place of science in citizenship. Again in this domain, longitudinal studies should be carried out in collaboration with sociologists.

3 . 4 Research in teacher education

The project revealed the importance of teachers in engendering student learning through labwork. A first need appears: to know more about the advantages and disadvantages of teacher education that addresses labwork in each country. The results should be used to propose new ways of training that promote team work on the part of students. In addition, this would allow teachers to be aware of and to carry out different tasks suggested as beneficial by the preceding research:

- conducting sessions of different types,

- implementing strategies
- developing materials for targeted labwork
- developing and providing for students relevant representations of science

Research should be carried out to promote an authentic collaboration between teachers and researchers, for instance through action-research.

Conclusion

A mutual understanding has been developed progressively amongst the numerous researchers in our consortium. It was necessary to discuss research methods in order to develop shared meanings and understandings as well as to overcome the issues involved in conducting research in a multilinguistic environment. Indeed, now that these issues have been identified they may well give rise to further specific studies.

The consortium is committed to continuing the collaboration that has been established within the project, in order to address methods of studying labwork, teacher education for labwork and the role of epistemology in science education.

Collaboration between researchers, teachers and policy-makers
should be one of the key aims of research
in Science Education in Europe for the next few years

5 . DISSEMINATION PLANS

Dissemination of the results obtained by the consortium of the project 'LABWORK IN SCIENCE EDUCATION' started before the end of the project.

1 During the project

From February 1996 to April 1998, the main outcomes have been :

- **24** scientific papers
- **32** publications in proceedings
- **30** communications in seminars and symposiums
- **7** theses

All the references are detailed in the annex 11

The results were used in courses for teachers (see also the four progress reports due to DGXII).

2 The European Thessaloniki symposium (April 1998)

The aims of this final symposium, as seen by the organisers, Pr D. Psillos and Dr P. Kariotoglou, as well as the co-ordinator and the group-leaders, were twofold :

- to promote a common reflection and mutual exchanges among the LSE members, especially the youngest researchers, at the end of the project, before the period of final writing.
- to promote an authentic collaboration with policy-makers coming from the 6 countries involved. In addition to the local authorities supporting and attending the symposium, two policy-makers per contractor country were invited.
  Finally 11 of them could attend :
    - France : Marie-Claire Méry
    - Denmark : Ole Goldbech, Kirsten Woeldike
    - Germany : Igmard Heber, Dieter Schumacher
    - Great Britain : Bob Ponchaud, Carolyn Swain
    - Greece : Christos Ragiadakos, Odysseas Valassiades
    - Italy : Giunio Luzatto, Giancarlo Marcheggiano

The symposium was also attended by Mrs G. Van den Brande, on behalf of DGXII.

They played the following roles during the symposium :

- Moderators of plenary sessions
- Co-ordinators of parallel groups where presentations of case-studies were done and discussed
- Participation in a round table : the eleven of them elicited the different roles they play in their countries and their impact on science education. They also thought of possible applications of the results. This was reported to the LSE consortium and a discussion followed on these different points as well as on possible collaborative work with researchers.

3 Further dissemination plans

3 . 1 Dissemination to teachers and teachers' associations

In the six countries involved in the project, a working paper summarising the results [Working papers 11 to 16] will be disseminated to teachers, especially the teachers who answered the different surveys. These working papers will be in the national languages. In most of the countries, there will be a meeting to present the results, as well.

The following associations will be informed either by a paper proposed to their Journal, either by a talk at the next meeting :

- Société Française de Physique (Journal : Bulletin de la Société Française de Physique) Union des Physiciens (Journal : Bulletin de l'Union des Physiciens), Association des professeurs de Biologie et de Géologie (Journal : Bulletin de l'APBG)

- Danish science teachers' Association
- German Physical Society (Journal : Physikalische Blaetter), German Association for Mathematics and Science teaching.
- Hellenic Union of Physicists (Journal : Epitheorisi Fysikis), Hellenic Union of chemists (Journal Chimika Chronika)
- Associazione Insegnanti di Fisica - La Fisica nella Scuola
- Association for Science Education (ASE) (Journal: Education In Science)

3 . 2 Teachers' education

Several members from the consortium participate in teachers' education in their countries. For instance, in France the information will be provided through the IUFM (Institut Universitaire de Formation des Maîtres) and the inspectors, as it already started in Lyon. In Denmark a course will be done to teachers, relying on the results . In Bremen and Dortmund, members of the consortium are integrated in a running process to improve labwork at undergraduate level. In Greece a special course has been planned on aspects of laboratory (week long residential in-service program organised by Pr P. Kariotoglou). In GB, the work has fed into a review of initial teacher training provision.

3 . 3 Dissemination to policy-makers

The dissemination will follow the first contacts established in Thessaloniki and the decisions made there. According to the type of centralisation, according to the on-going reforms (global in Italy and in Great Britain mainly, in given sectors in other countries), different types of collaborations were found. For instance, a letter will be written to all 16 ministers of Education in Germany on behalf of the LSE group and of the German Association for Mathematics and Science teachers. Associations of deans of German faculties, General Inspectors, will be approached. The Vice-Rector of the Thessaloniki University attended sessions of the Thessaloniki symposium and will disseminate the results to Universities and the Pedagogical Institute of the Ministry of Education.

3 . 4 Dissemination to researchers in science education

The members from the consortium will publish different papers in Scientific journals. For instance, soon the group-leaders will propose a synthesis paper to : International Journal of Science Education.
Several members are staff members at doctoral level. The results will become soon part of the teaching at this level.
Two symposiums will be organised soon after the end of the project, largely using the results and methods :

- Denmark : International Conference : 'Practical work in Science Education' (20-23 May 1998
  Danish conference : 'Det praktiske arbejde i naturfagene' (19-23 May 1998)
  Organisation : Pr Albert Paulsen

- Greece : First Greek Conference on research in Didactics of science and new technologies in Education (28-31 May 1998)
  Organisation : Pr Panargiotis Koumaras

[The communications from the LSE members at these conferences are to be found in the annex 11]

ESERA [European Science Education Research Association]

This association has a letter available on the web. A letter will be sent with the abstract from the final report, the list of working papers, and the contact points. A talk will be proposed to the next meeting in Keele.

EARLI [European Association for Research in Learning and Instruction]

Presentations will be made at the next meeting of EARLI in Goteborg, 1999.

ICPE [International Commission for Physics Education. Commission C14 of the IUPAP]

At the beginning of the project, the newsletter accepted a summary of the planned research activities. Very soon a summary of the results will be proposed as well as the list of the Working Papers and the Internet address where to find them.

Conclusion

The members of the consortium are numerous to consider that a mutual understanding has been settled progressively in their community. Research methods have been discussed. In depth discussions provided commonality of thinking. Scientific concepts used specifically in research in science education are now common, in spite of problems of language which are now identified and will give rise to specific studies.

Groups of members of the LSE consortium are committed to future collaborations.

6 . AKNOWLEDGEMENTS

The enthusiasm and time contribution of the students and teachers who participated in this project and made the research possible is gratefully acknowledged. In addition, the project would not have been possible without administrative and financial support provided by the host universities.

ϖ France	Université Paris Sud XI	for the group DidaScO
	Université Lyon II	for the group COAST
ϖ Denmark	University Roskilde and FIFU	
ϖ Germany	University of Bremen	
ϖ Great Britain	University of Leeds	
ϖ Greece	University Aristotl of Thessaloniki	
ϖ Italy	Universita La Sapienza in Roma	

The Consortium is indebted to the researchers quoted in the different working papers, and especially in the list of selected references presented in Part 3 of this report.

The Consortium of the project gratefully acknowledges the financial and administrative support given by members of DGXII of the European Commission through the duration of the project.

7 . ANNEXES

The annexes to the final report of the project *'Labwork in Science Education'* are constituted by

- ten Working Papers, in English (WP10 concerning biology labwork in France, in French as well) . Each of them has an ISBN from the country of one of the main author. The list is given below.
- Annex 11 giving all the references of the publications and communications outcomes of the project
- Six Working Papers in national language aimed specifically at dissemination towards teachers. They are taken into account in part 6 *'Dissemination and exploitation plans'*

WORKING PAPERS

∗ Working paper 1 ∗

A MAP FOR CHARACTERISING THE VARIETY OF LABWORK IN EUROPE

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

Language : English . In each country, translation in its own language

∗ 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, 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, 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, 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, Francisco 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, Petros 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 OBJECTIFS DES TP DES SCIENCES DE LA TERRE ET DE LA VIE DANS LES LYCEES FRANÇAIS

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

Language : French and English

ANNEX 11

PUBLICATIONS AND COMMUNICATIONS

from the consortium during the duration of the project *'LABWORK IN SCIENCE EDUCATION'*

WORKING PAPERS 12 TO 17

These working papers provide summarised results from the project, in French, Danish, German, English, Greek and Italian. They will be available in October 1998.

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.

23 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.