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LABWORK IN SCIENCE EDUCATION

* WORKING PAPER 14 *

LABWORK IN SCIENCE EDUCATION: EXECUTIVE SUMMARY

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Improving Science Education: Issues and Research on Innovative Emprical and Computer-Based Approaches to Labwork in Europe

Short Title : Labwork in Science Education

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Outcomes

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

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ABSTRACT: *'Labwork in Science Education '*

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

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

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

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

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

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

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

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'LABWORK IN SCIENCE EDUCATION': EXECUTIVE SUMMARY

M-G. Séré, J. Leach, H. Niedderer, A. C. Paulsen, D. Psillos, A. Tiberghien, M. Vicentini

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'*. [Working Paper 1]

- A survey of current practice in the use of labwork. This is referred to as the survey of *'Current labwork practices'*. [Working Papers 2 and 3]

- 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'*. [Working Paper 4]

- 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'*. [Working Paper 5]

- A survey of the learning objectives attributed to labwork by teachers, referred to as the survey of *'Teachers' objectives for labwork'*. [Working Paper 6]

- A set of 23 case studies of labwork practice, together with an analysis of the effectiveness of labwork in promoting learning. [Working Papers 7 and 8]

A list of working papers is appended to this report.

Management and realisation of the work

The Consortium involved 7 research groups from 6 European countries

		GROUP-LEADERS
France	Université Paris-Sud XI; DidaScO Group	Prof. M-G. Séré Project Co-ordinator
	Université Lyon 2; COAST Group	Dr. A. Tiberghien
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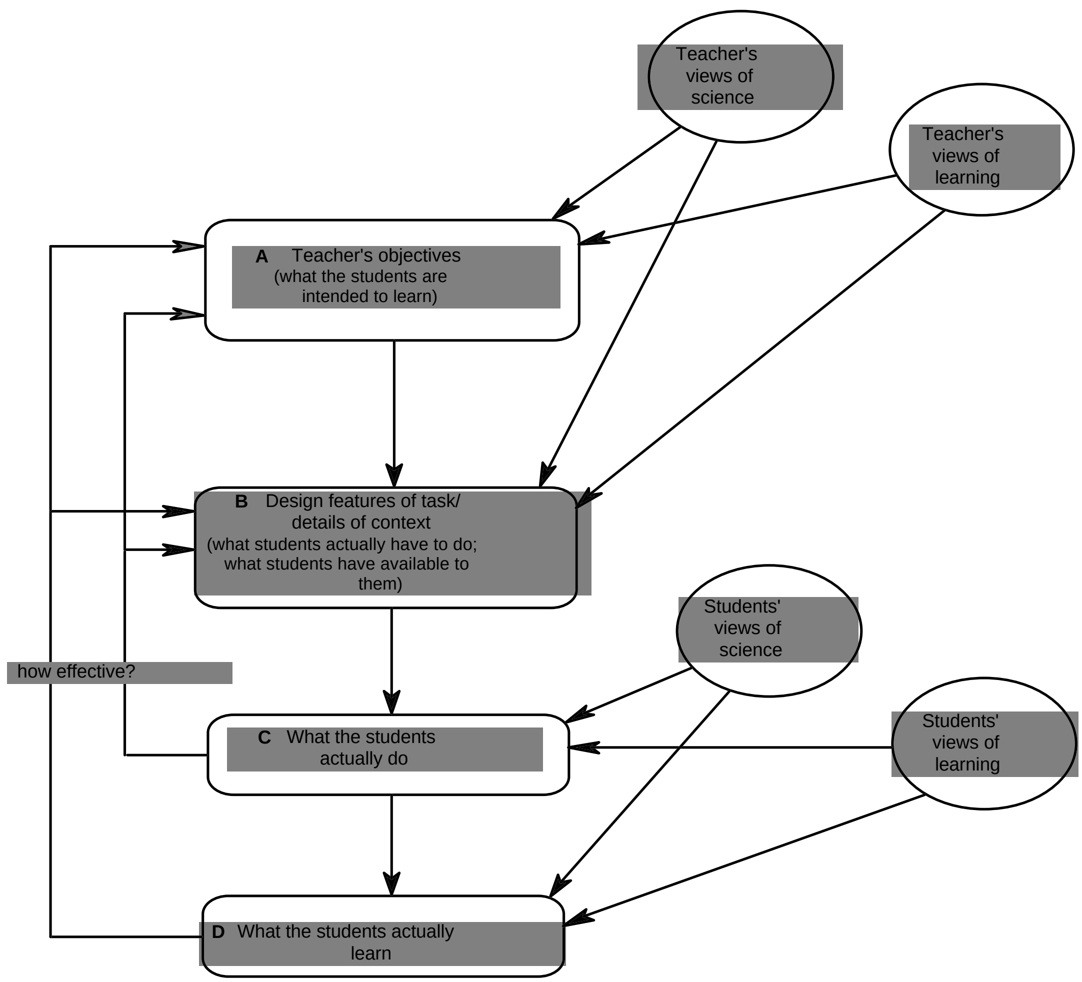
Prof. M-G. Séré (DidaScO group) was responsible for the overall co-ordination of the work. The survey of current labwork practices was managed by the COAST group. The survey of students' images of science and the production of the map of the variety of labwork were co-ordinated by the British group. 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' [See Working Paper 1]

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' [See Working Papers 2 and 3]*

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' [See Working Paper 4]*

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' [See Working Paper 5]*

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' [See Working paper 6]]*

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 [See Working Papers 7 and 8]

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.

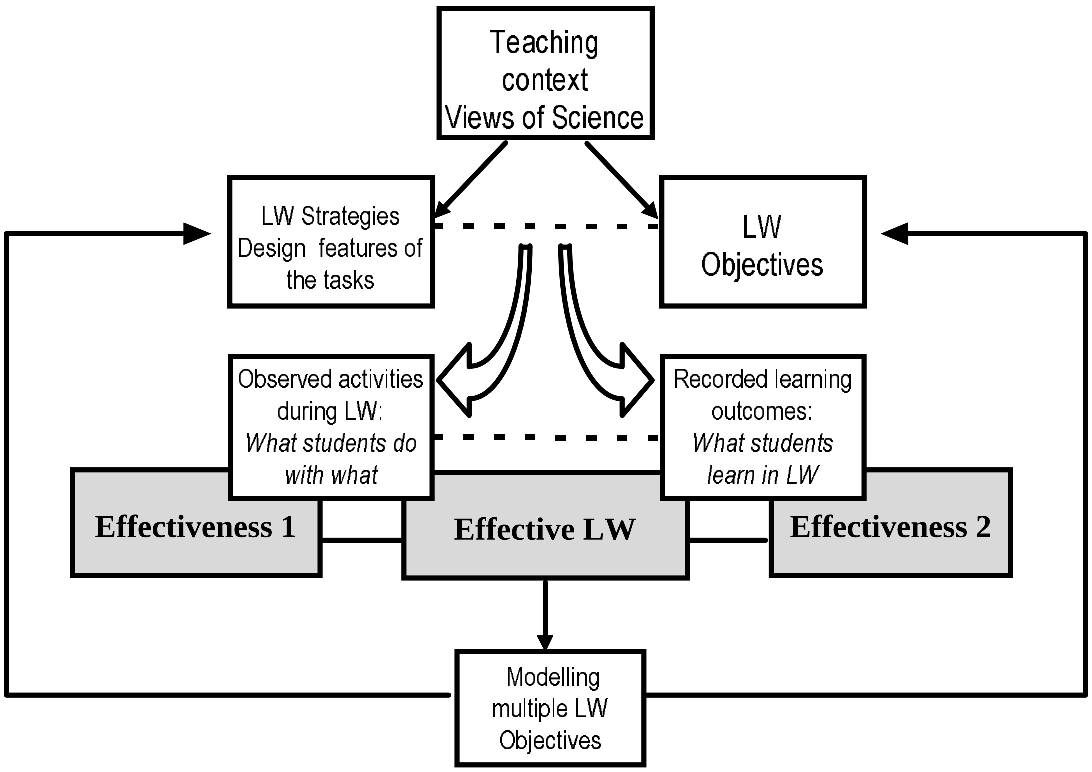
A classification of the case studies

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.

APPENDIX: WORKING PAPERS FROM THE LSE PROJECT

* Working paper 1 *

A MAP OF THE VARIETY OF LABWORK IN EUROPE

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

Language : English.

Availability: The Secretary, LIS, CSSME, The University of Leeds, Leeds LS2 9JT.

* Working papers 2 and 3

SCIENCE TEACHING AND LABWORK PRACTICE IN SEVERAL EUROPEAN COUNTRIES

Availability: UMR GRIC - Equipe COAST (Communication et Apprentissage des Savoirs Scientifiques et Techniques), CNRS - Université Lyon 2, 5 Avenue Pierre Mendes France, 69676 BRON Cedex 11, France.

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

Availability: The Secretary, LIS, CSSME, The University of Leeds, Leeds LS2 9JT.

* 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

Availability: M. Vicentini, Laboratorio di Dadattica delle Scienze, Università 'La Sapienza', P.le Aldo Moro, 2, 00185 Roma, Italia.

*** 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

Availability: Manuela Welzel, Physics Department, University of Bremen, PO Box 330440, D-28334 Bremen, Germany

*** Working paper 7 ***

CASE STUDIES OF LABWORK IN FIVE EUROPEAN COUNTRIES

Editors : Dimitris Psillos and Hans Niedderer

Language : English

Availability: D. Psillos, School of Education, Aristotle University of Thessaloniki, Thessaloniki 54006, Greece.

*** 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

Availability: D. Psillos, School of Education, Aristotle University of Thessaloniki, Thessaloniki 54006, Greece.

*** 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

Availability: H. Niedderer, Physics Department, University of Bremen, PO Box 330440, D-28334 Bremen, Germany

*** Working paper 10 ***

LES OBJECTIFS DES TP DES SCIENCES DE LA TERRE ET DE LA VIE DANS LES LYCÉES FRANÇAIS

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

Language : French and English

Availability: M-G. Séré, DidaScO, Bât. 333, F-91405 ORSAY Cedex, France.