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LABWORK IN SCIENCE EDUCATION

* WORKING PAPER 9 *

Category Based Analysis of Videotapes from Labwork (CBAV)

- Method and Results from Four Case-Studies

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Improving Science Education: Issues and Research on Innovative Empirical 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/tser/src/ct2001w.htm.
The abstract of the project provided on this site is given on the next page.

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.

* WORKING PAPER 9 *

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1 Introduction

Labwork in science education is a complex situation, it involves very different kinds of activities such as manipulating an apparatus, doing measurements, talking about physics, and making predictions.

The first basic idea of our category-based analysis of videotapes from labwork (CBAV) is to allow an analysis of such complex situations for a rather large amount of recorded data (up to 30 hours) to find some coarse but nevertheless important conditions for improving labwork. The aim is to find relations between characteristic contexts of labwork defined mainly by the resources students use, such as manipulating apparatus or doing measurements, and the students verbalisations in relation to basic concepts of physics. Talking about physics during labwork is assumed to be an important indicator for effective learning of physics (Bliss 1996).

The second basic idea for developing and applying the CBAV method is to find a method which would allow us to get a bigger amount of data from analysing more videotapes than would be possible by doing a detailed interpretive analysis and analysing learning processes during labwork; to find a method which would allow us a rather rough and fast analysis - compared with a qualitative interpretive analysis of learning processes using transcripts from audio and video tapes.

Intended results are simple structures and causal relations in labwork. The CBAV method is based on categories both for contexts and intended activities related to physics learning, which are applicable by watching videos from labwork more or less in real time. The categories reflect on one side contexts of labwork as independent variables of the relations and, on the other side, categories for verbalised knowledge as an indicator for physics learning.

Relevant categories for contexts of labwork are rather obvious. They are defined mainly as different important resources being used, such as apparatus, measuring devices, lab guides, or interaction with a tutor. Similar categories have been defined by several other authors (Okebukola 1985; Kyle et al. 1979; Tamir and Lunetta 1981).

So, by the results of this analysis, the following types of questions could be answered:

- How much time during lab is devoted to work with the different kind of contexts and resources?
- Which of the contexts or used resources were more or less effective in the sense that they promote students doing the intended activities such as talking about physics?

The more difficult part is to define categories describing the intended activities which might contribute to better learning during labwork. It is immediately clear that no direct results about learning outcome can be found by a method like this. So the idea is to find observable categories, which experts from science education might accept as indicators for learning. Now, as we know from the results of survey 3, there are many different objectives of labwork in science education. We decided to focus on only one of these objectives, the contribution of labwork to the objective "to link theory and practice". As the context of labwork is always related to the real world objects, and this "world of objects and events" is described by our context categories, we in addition have to find categories which show that students use some theory in these contexts, that they use some elements of the "world of theories and models" (Tiberghien et al. 1995). Therefore, we decided to use categories of the verbalised knowledge as indicators for using theory in labwork. Especially, two categories, namely verbalising physics knowledge (KP) and verbalising the relation between objects of the real world and physics concepts (KTP) were of special interest (Bécu-Robinault 1997).

2 The method

Methods using categories for analysing teaching and learning processes have been used a lot throughout empirical research in education. The specific structure of our method is given by the following features:

- instead of observing real processes of teaching we use video tapes. This offers a chance of looking at the same processes again and again, and with different observers.
- the method and the categories used are related especially to learning situations with labwork in science education.
- the analysis itself works more or less in real time, without transcripts and thereby allows to review a bigger amount of data.

Especially by this last feature, we see this method as a complementary method to analysing video tapes by using careful transcriptions and qualitative interpretive methods of analysis, which have been used extensively in our four groups for a long time (Aufschnaiter&Welzel 1997, Bécu-Robinault 1997, Fischer 1994, Niedderer&Goldberg 1995, Petri&Niedderer 1998, Tiberghien & Megalakaki 1995, Welzel 1997).

2.1 Earlier Methods using categories for analysing labwork in science education

We found three main approaches to analyse labwork using categories in the literature:

- Lab sheets or lab guides can be categorised concerning the intended behaviour of the students e.g. the Laboratory Structure and Task Analysis Inventory LAI (Tamir & Lunetta 1978) and the Laboratory Program Variables Inventory LPVI (Abraham 1982).
- The written lab protocols can be categorised to assess the students' performance in labwork e.g. the Practical Tests Assessment Inventory PTAI (Tamir 1989, Okebukola 1984).
- The activities of students during labwork sessions can be observed and categorised. This was done by Penick et al. (1976) with the Science Laboratory Interaction Category (SLIC) and more recently by Stein (1990).

We focus here on methods to analyse activities during labwork. The Science Laboratory Interaction Category (SLIC) is mainly used to find and describe activities in practical laboratory work, especially to describe interactions between students and teachers. Activities of the learner are ordered by 10 categories (showing, manipulating apparatus, transmitting information, asking questions, listening, reading, writing or recording data, getting supplies, non lesson related behaviour). Nearly all of our CBAV categories for contexts can be found in the SLIC categories, e.g. manipulating apparatus and recording data are used in quite the same way. But there are also additional categories which are defined according to the different purposes of the two methods. Since SLIC was developed to investigate interactions in labwork, it has various categories to describe different aspects of interactions (showing, transmitting information, asking questions and listening) which would be coded in the CBAV with a single category "contact to third person". On the other hand, since we also want to investigate labwork using modern technologies we included categories in the CBAV, which refer to the use of computers. But the main difference has its ground in our purpose to investigate cognitive processes and their relation to labwork contexts. Therefore we developed a second grid of categories referring to verbalised knowledge (see 2.2 and 2.3). This is a unique feature of our method.

SLIC was used in different ways, e.g. to investigate what students do in college labwork in different disciplines and levels (Kyle et al. 1979) and to find out if and how observed behaviour correlates both with the results of a knowledge test and with the learner's attitude to laboratory work (Okebukola 1985). This is an attempt to combine cognitive aspects and behaviour in laboratory. But while CBAV focuses on cognitive processes during labwork, Okebukola investigates correlations between behaviour in labwork and test performance.

A method most similar to CBAV was used by Stein et al. (1990). Stein structured a labwork session in three successive phases (set-up, data collection, analysis) and categorised verbal statements of students during each of these phases, using categories such as off-task, empirical, and conceptual level. "Empirical" is very similar to our category "technical knowledge (KT)", "conceptual" corresponds more or less to "physics knowledge (KP)". They also analysed the relation between use of computers and students' knowledge verbalisations.

2.2 The CBAV categories for contexts of labwork

As pointed out in the introduction, we use two types of categories, one type for differentiating between different typical contexts of labwork, the second type describing intended mental activities related to the objective "to link theory to practice". We assume that the context in labwork is to a large extent determined by the resources being used.

CBAV categories of LABWORK CONTEXT			
Category		***Description***	***Examples***
Other	**O**	Activities not at all related to the lab.	Talking about last nights' TV
Interaction with third person	**3.P**	A third person can be the teacher, the tutor, other students, or similar.	Tutor helps to solve a technical problem and talks to the students
Labguide	**LG**	Using the labguide.	Using the LG to plan what to do.
Paper and pencil	**PP**	Using paper and pencil. Students are writing or reading in their own protocol.	Preparing tables for measurement data, drawing a graph.
Mani-pulation of apparatus	**MA**	Using the apparatus and devices. Carrying out experimental set up or preparing a measurement	Building up an electrical circuit; taking a test-measurement; having a problem with the apparatus.
Measure-ment	**ME**	Resources used are apparatus <u>and</u> paper and pencil	Taking the pendulum's amplitude and writing the value down
Calculation	**CL**	Using a (pocket) calculator or a special software like Excel for this purpose or doing a direct calculation with paper and pencil	Calculating a physics quantity from the measurement data
Computer measurement	**CME**	Replaces category ME in the case of computer-based measurements in labwork (MBL)	Reading the amplitude from the graph on the computer screen
Computer model building	**CMB**	Using a modelling software (STELLA, Cabri-geometre II) to create a model structure or make changes or add new relations.. (special use in FC1, see below)	Building a model of an oscillating spring and incorporating a frictional force into this a model.
Computer model use	**CMU**	Using a modelling software (STELLA, Cabri-geometre II) when a model is ready and only parameters in the model are changed or students run a simulation (special use in FC1, see below)	Trying to predict measurement values by the model (simulation of experiment)

Special comments on categories and differences of their use in different case studies

O

If, for instance, students have to wait while doing a measurement and they talk about TV, the category "Other" is not ticked, but the category "Doing measurement" (ME). Or if measurement is running with MBL and they talk about TV, the tick is made for CME. If the tutor is talking with students about old protocols, a cross is made in this category, if the talk is not important for use of knowledge in this running lab. Otherwise a cross is made in "Interaction with third person".

3.P

Which persons are interacting, will be marked in the comment column. If a teacher or tutor is talking and students don't listen and go on with the experiment (or anything else), this category is not used. In FC1, this category is used, when the teacher is speaking only to the observed pair.

LG

Equivalent to labguide is black board, written lab material from a course or written short info given to the students. In FC1, this category is also used, when the teacher is speaking to the whole class (because this is a « cours-TP », a kind of lab class). This explains why LG is used in FC1 much more than in the other cases.

PP

In GE2 also applied when computer is used instead of paper and pencil but with the same purpose. Especially in FC1 also used, when students write down their answers to the given questions ; this is a way to formulate their ideas and to discuss one with another.

ME

The students are doing measurements in a typical routine of automatical activity. It covers the time between starting the measurement and writing down the measured values. Variations of the apparatus between two measured values shorter than 30s are not recorded, so that routines of measurements which involve quick changes of the apparatus are all in this category.

CL

Calculations during which students write down a value are marked in categories PP and CL.

CME

This is never used in FC1.

CMB

First simulation of a new model or after a change of the basic structure is included in this category (not CMU).

In FC1, at rare occasions, they can draw some additional features on the given model, this activity is then coded CMB.

CMU

In FC1, the students use the computer-based model ("Cabri-geometre II"); they can modify the shape of the drawing according to the physics model of geometrical optics; this is also coded CMU.

2.3 The CBAV categories for types of verbalised knowledge

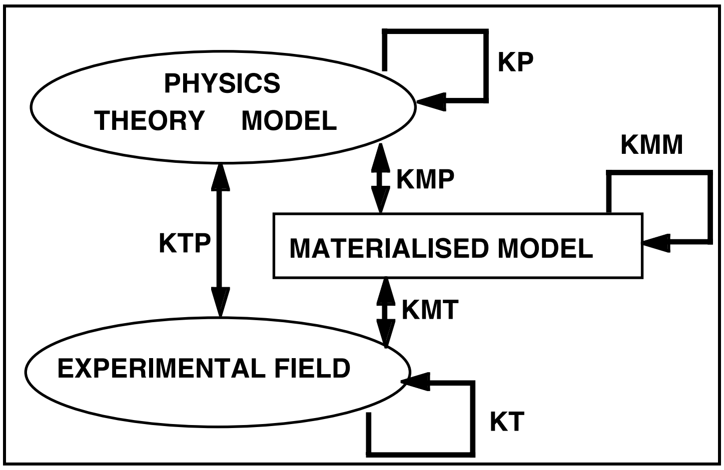
After having defined the categories for different typical contexts of labwork, we now start to define categories for intended mental activities related to the objective "to link theory to practice". We assume here, that talking about physics means to verbalise important knowledge in the different contexts of labwork and that it is a viable indicator for cognitive processes contributing to the objective "to link theory to practice". The following table gives the main categories used by all case studies. Some additional categories especially used in FC1 with a specific theoretical model are defined afterwards.

CBAV categories of VERBALISED KNOWLEDGE during labwork			
Category		***Description***	***Examples***
Technical knowledge	**KT**	Students use knowledge more related to technical apparatus. Often related to the handling of apparatus	Talking about how to operate an oscilloscope; adjusting the interface software
Physics knowledge	**KP**	Students use physics knowledge, e.g. using words referring to physics	Talking about how to determine the phase from an oscillation diagram on the screen
Technical knowledge and physics knowledge additional	**KTP_a**	Students use physics knowledge and technical knowledge together (GE1, GE3)	Talking about how to carry out a measurement for a certain physics quantity
Technical knowledge and physics knowledge intertwined	**KTP_i**	Students use physics knowledge and technical knowledge intertwined, they establish a relation between objects/events and the physics knowledge (FC1, GE2)	Talking about how to measure a certain physics quantity with the experimental device or about the image given by the beam of the lamp on a screen.
Mathematical knowledge	**KM**	Students use formulas in their statements or other mathematical knowledge	Describing the mathematical properties of a measured curve

These categories are used in all four case studies. In FC1 - and to some extent in GE2 - a KTP is being used when students talk about links between physics concepts and real world objects and events of the experiment in the lab. In GE1 and GE3, KP is often used instead of KTP assuming that a link to real world objects and events is always present for the student in the lab situation.

Special additional categories for knowledge verbalisation used in FC1

The following figure shows a general model, used by the COAST group (Tiberghien et al.). A special meaning is given to the categories used by all (see above) and some additional categories being used only in FC1.



Out of this graphical representation, the following definitions of additional CBAV categories are to be seen:

Additional CBAV categories of VERBALISED KNOWLEDGE used in FC1			
Category		***Description***	***Examples***
Knowledge Materialised Model	**KMM**	When students describe what they see on the screen of the computer in terms of geometry	"OK go on the half-circle there where is written « move » no there on the screen"
Link Materialised Model to Physics	**KMP**	When students interpret what they see on the computer screen in terms of physics theory.	"[it corresponds] to the refraction yes this point go go go go go here have you seen (?) and even more ha that's too bad they have not done [the second part of the reflected ray]"
Link Materialised Model to Real Experiment	**KMT**	When students establish a relation between the content of the materialised model and the objects/events they have observed on the real experiment	"Em : so that is the bea(: :) how do you call it (?) how did we call it (?) ... the ray which was around ; Ade : oh yeah the parasite light here ; Em : yeah"

Special comments to categories and differences of their use in different case studies

In FC1, we have to notice that, when the context is CMU or CMB (working with the "materialised model" on the computer screen) the categories KMM, KMP and KMT are necessarily used to characterise the verbalisation of knowledge.

KT

KT is used in FC1, when students are speaking about the world of real objects and events; for example " look, that is easy. You take the rule and you see what you get. That is nothing but the glass".

KMM

This category is also used when students are managing the functionality of the software.

2.4 The grid of categories

The method is used more or less in real time, a tick is made every thirty seconds, the tape is going on continuously, so the decisions to tick have to be taken very rapidly.

The following table illustrates how these categories are used with a special grid (worksheet):

Time	Resource										Knowledge							Comments
	O	3.P	LG	PP	MA	ME	CL	CME	CMB	CMU	KT	KP	KTP	KM	KMM	KMP	KMT	
0,0			1								1							what is the astronomical telescope composed with ?
0,5			1															
1,0			1								1		1					
1,5										1								they load lunette2
2,0										1					1			
2,5										1								
3,0										1								
3,5										1								
4,0										1								some problems for other computers

2.5 Reliability of the CBAV categories

We had two main questions with respect to the reliability of the CBAV method, and two corresponding methods of comparison:

- How consistent does one coder use the CBAV categories? Each coder performed the CBAV with selected episodes of his videos again.
- How consistent do different coders use the CBAV categories? Selected episodes were exchanged between several coders and analysed again.

The length of the analysed videos varied between 20 min and 45 min.

In order to determine, how consistent the categories for labwork contexts and those for knowledge were used, we calculated two mathematical indicators.

Mathematical indicators

- ***C***: a global indicator how well categories for the labwork contexts were used.

C is defined as the number of marks that were in the same category at the same time step divided by the total number of marks made of two observers.

C varies between 1 (two coders or one coder in two trials marked the same categories all the time) and zero (both marked different categories all the time).

- an indicator that specifies how well the decisions of two coders correlate for each category. φ is defined as:

$$\varphi = \frac{A \cdot D - B \cdot C}{\sqrt{(A+B)\cdot(C+D)\cdot(A+C)\cdot(B+D)}}$$

A is the number of cases where coder one and coder two marked the same labwork context at the same time-step, D is the number of cases both observers did not mark the same labwork context at the same time step, B is the number of cases coder one marked a labwork context at a certain time step while the second coder did not and C is the number of cases where coder two marked a labwork context while the other did not.

φ = 1 means, that both coders always agree; φ **=** -1 means, that they always disagree. The reader should bare in mind, that low positive values of φ still indicate a positive correlation.

In addition we calculated the indicators above in the **worst** or the most strict case and the **best** case, responding to the fact that crosses applying to the same contents of the video are sometimes made at different time steps. This can be seen in similar patterns of two coders, which are shifted by one time step. The best case is considered to be the most meaningful one, since shifts of 30 s are likely to happen.

Results of mathematical indicators

	Labwork Context Categories	**Verbal Knowledge Categories**
C, one coder	0,8 - 0,88	0,87
φ, one coder (single categories)	0,66 - 0,80	0,5 - 0,65
C, two coders	0,7 - 0,83	0,3 - 0,8
φ, two coders (single categories)	0,55 - 0,72	KT: 0,55 KP: 0,3 KTP: 0,4

As a global result with respect to "labwork context categories" it can be said: the time budget of the single labwork contexts and the global pattern can be reproduced quite well. From the data about verbal knowledge categories, we conclude that the time budget regarding knowledge is trustworthy. From the results with two coders, we conclude, that the time budget of a labwork context is comparable (intersubject reliable).

The low φ values and the large standard deviations (KP: 0,3±0,4 and KTP 0,4±0,4) indicate that strong deviations can happen between the coders. This goes along with the similar definitions of these categories by Haller (GE 1) and Sander (GE 3) in contrast to those of Buty (FC1) and Hucke (GE2). In general the φ value confirms that Haller (GE1) and Sander (GE 3) use KP and KTP more similar to each other (KP max φ = 0,5 ± 0,3, KTP very seldom used by both coders) than to Hucke (GE 2) (KP : 0,2 ± 0,4, KTP: 0,3 ± 0,3). In a similar way, the φ value indicates that Buty (FC1) and Hucke (GE 2) use KP and KTP quite similar (0,5; 0,5). In general it can be said that comparing statements concerning KP and KTP have to be treated with great care. Therefore we used the sum of both categories for calculating densities of verbalising physics knowledge in section 3.4.

Further comments on reliability

We watched the videos in our group and discussed our individual interpretations of the categories. If we compare qualitatively how different coders use the CBAV we come to the following factors that influence the reliability.

Factors inherent to the method

- shifted pattern: this effected has been described above.
- observed person: we concentrated on one student -the most active one- concerning the activities. Sometimes we swapped the focus to another student when his or her actions becomes dominant. Problematic are situations with two students working co-operatively.

Factors linked to labwork context

- Dominating activity: Sometimes there are parallel activities making a decision for one category difficult.
- Quick changes: Sometimes, the activities move through different categories on a rather short time scale, with much less than 30 seconds. Example: A student measures, looks quickly into his labguide and starts to manipulate an apparatus. In this case some coders tend to neglect a category while others mark it.
- Discrimination of categories: Some categories are difficult to discriminate from other categories. This applies to MA (manipulating apparatus) and ME (measuring) in the German case studies (GE 1, GE 2, GE 3). Similarly the reliability is influenced by the fact that the coders have to be familiar with the learning environment.
- Completeness of categories: Another problem arises when students talk without doing something that can be categorised as a labwork context. While some coders decided to

consider these categories as MA (GE 3), others categorised these actions as belonging to the categories that were chosen before and afterwards.

Factors linked to verbal knowledge

- Different definitions of KP and KTP (see above).
- Different tendency to accept a statement as "verbalised knowledge".
- Other factors: Some coder made in certain cases two crosses at one time step while the others marked just one category.

In contrast to other groups which extensively trained their methods to categorise actions in labwork (Okebukola 1985) until they reached a high degree of agreement, in our case there was no special training before using the categories. Because of the distances between the working groups, only the verbal definitions, which were developed during a two day workshop, were the common basis of the different coders. A further method to check the reliability of the method would have been to have a complete video or a longer episode analysed again by different coders. This remains a further step in the elaboration of the method.

2.5 Definition of effectiveness in this context

The effectiveness of labwork is obviously related to the objectives of labwork. The CBAV method was developed with the main objective for labwork "to link theory to practice" in mind. According to the results of survey 3, this is one of the three most important objectives for labwork, others being "to learn experimental skills" and "to develop methods of scientific thinking" (see Working Paper WP6). It seems important to distinguish between two levels of outcomes from labwork: Intended activities *during* labwork and learning outcomes *after* labwork. Now, to link theory to practice stresses an important activity *during* labwork, namely to relate science theory to what is going on during the lab. One form of analysing this link between theory and practice is to look for students' verbalisations of physics knowledge during labwork.

Similarly, with respect to effectiveness of labwork, we have two kinds of effectiveness related to the two kinds of outcomes. Effectiveness 1 is the relation between certain features of labwork such as contexts, labguides, tasks etc. and intended activities such as to talk about physics in the context of lab. Effectiveness 2 then is the learning outcome after labwork, in many cases after a whole course including labwork. This definition of effectiveness 1 and effectiveness 2 is given and explained in more detail in "the MAP" (Working Paper WP1) and in summarising results of case studies (Working Paper 8).

With respect to the CBAV method, only effectiveness 1 is important (see Fig A, below). By defining the categories of contexts (see section 2.2) we have defined the teaching context variables (**S_i**) which influence the intended activities "to link theory to practice". By defining our categories for verbalised knowledge (see section 2.3) we have defined our variables to analyse the intended/observed activities of students during labwork (**A_i**), e.g. talking physics, as an indication of linking theory to practice. So by relations between the variables of context and the variables of verbalised knowledge, we come to results about effectiveness 1 (**S_i ==> A_i**). The categories have an *underlying hypothesis*: Verbalisation of knowledge is an important step towards linking theory to practice and furthermore to learning physics (**A_i ==> L_i**). So we use categories related to the type of verbalised knowledge as an *indicator* for intended activities and for learning (Bliss 1996). If students during labwork talk about technical knowledge or physics knowledge as defined in these categories this clearly indicates some cognitive processes happening during labwork. Of course, there can be additional cognitive learning effects without verbalisation, but we do not know anything about them. So, it seems relevant to analyse which contexts and resources of labwork contribute more or less to talking about physics.

The two different meanings of effectiveness are shown in the following general scheme:

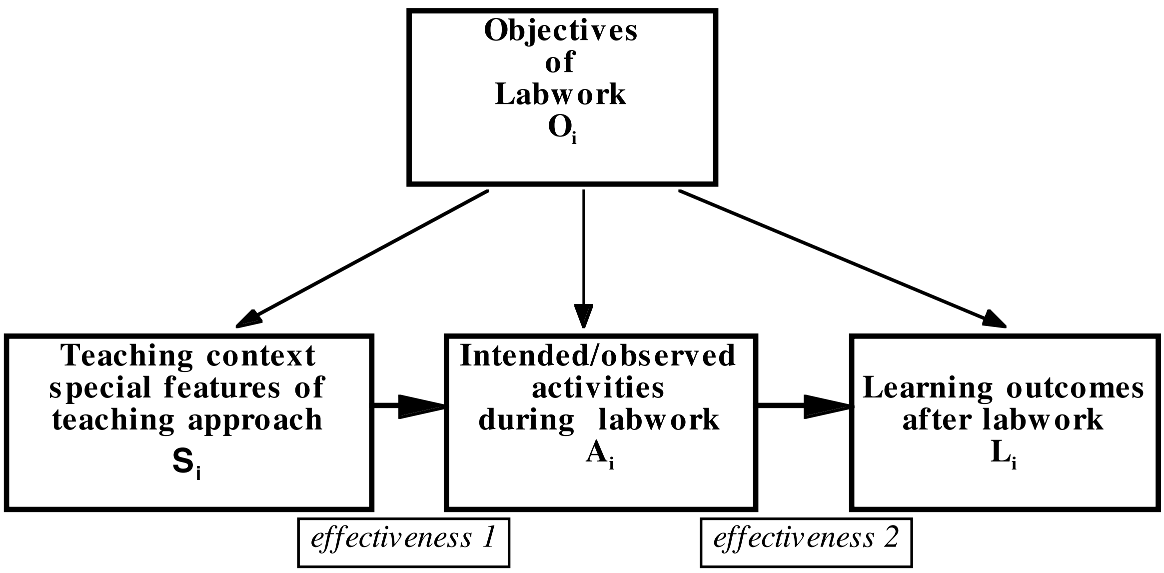


Figure A: Two different meanings of effectiveness of labwork

3 Labwork contexts and knowledge verbalisation - empirical results related to labtime

3.1 Overview of the four case studies using the CBAV-method

3.1.1 How much time has been analysed in the four case studies?

The whole sequence in FC1 has been videotaped and analysed during approximately 13 hours. In GE1 altogether 15 hours, in GE2 altogether 11 hours, in GE3 altogether 12 hours of labwork were analysed. The difference between FC1 and others is that the same student is observed during 13 hours, whereas in GE1, GE2, GE3 partly different students are observed.

3.1.2 Modelling In Geometrical Optics Using A Microcomputer (FC1)

In this case study the domain of physics knowledge is geometrical optics. The observation takes place in the last year of French upper secondary school, in a real class with fourteen students working in pairs. They are managing « cours-TP » activities during an eight week long sequence, a session of two hours a week. That means that the teacher integrates a lecture with the performing of experiments by students. Thus he is giving both theoretical elements and instructions about the way to perform the experiments : he often speaks.

In this sequence, the students are confronted both with a standard apparatus where they can perform classical experiments in geometrical optics, and with a dynamic, computer-based representation of this experimental device ("Cabri-geometre II"). This dynamic representation's behaviour is consistent with the model of geometrical optics. The students had never used the software before.

As often in geometrical optics, the experiments are rather simple to achieve (not necessarily to interpret): it means that the measurements are limited, an important part of the experiments is qualitative.

We have divided the whole sequence in 15 situations, according to the teaching content of each situation. One pair of students is videotaped all along the sequence, and the focus is put on the activity and verbal productions of one student in the pair.

3.1.3 Development of situated cognition during labwork activities of university students (GE 1)

With this case study we investigate the individual development of situated cognition during traditional labwork activity. All experiments are carried out by students in groups of two in an traditional way, as usually taught at German universities, with revised labguides. The revision of the labguides took place on the basis of previous results with the aim to encourage the students to connect theory and experiment, which is one main objective of labwork, as we know from results of survey 3 (Working Paper WP6). The encouragement of the students was realised by posing questions, asking the students to check their measured data or asking them to talk about the physics concepts. For example the labguide of the lab session 3 included all graphs, which the students should measure and suggestions to check the gathered data by comparing them with the pictured theoretical results .

At the beginning of an experiment the experimental devices were more or less set up. In the three labwork sessions students had to observe and determine physics quantities and relations between them. In the first experiment students had to verify a standard law. In the second one the students were supposed to measure the temperature-dependency of two resistors. And in the last labwork sessions the students were supposed to get familiar with filter-circuits.

Data have been gathered in labwork sessions at university level in Bremen during the winter term 1996/97. The course is designed for physics students studying physics in the second year in the content area of electrodynamics. Till now five videographed labwork session have been analysed with CBAV. We decided to examine one labwork group during 3 different lab sessions:

- **lab 1:** Coulomb-law
- **lab 2:** temperature dependence of resistors
- **lab 3:** frequency dependence of high- and low-pass-filters.

In addition two other groups of students doing the third labwork session has been analysed.

	lab 1 (l1)	lab 2 (l2)	lab 3 (l3)
group 1 (g1)			X
group 2 (g2)	X	X	X
group 3 (g3)			X

This selection enables us to investigate the influence of the structure of a labwork session, e. g. the written labguide of the activities of students and the statements of knowledge but also the activities of a specific group of students during different labwork sessions.

3.1.4 The link of theory and practice in traditional and in computer-based university laboratory experiments in Germany (GE2)

In this case study, traditional labwork is compared with labwork using the computer for measurement and for model building. The objective of the study is to evaluate the effectiveness of labwork at university level in Germany using „the link between theory and practice„ as a criteria. The study took place in the introductory physics laboratory course (2nd year) at the University of Dortmund. The results presented in this Working Paper are related to a classical laboratory experiment in mechanics (Pohl's pendulum as an example for an enharmonic oscillator). Three experimental designs of this experiment have been applied: (1) without computer, (2) with computer used for measurement only (interface system CASSY) and (3) with computer used for measurement and modelling (model building system STELLA). Students work in groups of two in the laboratory. They are supervised by an older student which is supposed to help in case of problems and to check the students' knowledge about the experiment. The data analysis is usually done at home. Because of the detailed lab manual, this type of labwork can be referred to as "cookbook" labwork.

3.1.5 Learning processes in computer-based physics labwork in a course on Newtonian mechanics (GE3)

In this case study the effectiveness of computer-based labwork in a first year university physics course in mechanics is investigated. The computer is used in several labwork sessions as a tool both for data collection (MBL) and model building (MBS), representing the basic areas of experiment and theory. The overall topic of the course is Newtonian mechanics. The main data have been collected from an innovative course with pre-service teacher students, comparative data have been taken from a parallel course of physics master students with 'traditional' labwork also in first year of mechanics.

We have analysed five labwork sessions with the CBAV including labwork with computers and without computers. All labwork sessions are performed by one group of two students in the innovative course:

lab Nr.	content	computer-tools
lab 1	linear motion	none
lab 4	linear oscillation	MBL and STELLA in one session
lab 5	forced linear oscillation	MBL and STELLA in one session
lab 6	movement in the plane	none
lab 7	torque and circular motion	none

In lab 1 students work with a rather open labguide and have to make and measure different forms of linear motion. In lab 4 students investigate linear oscillation of a spring and successfully construct a STELLA model. In lab 5 students have to determine the resonance curve of a spring. During modelling students have severe problems, because of a lack of content knowledge. In lab 6 students measure the centripetal force of a moving mass and in lab 7 students are supposed to determine the torque of several bodies. In this lab students use the most detailed labguide.

3.2 The time budget of labwork contexts in different types of labwork

First results are shown in table 1 and 2 about the percentage of time which students work with the different contexts and resources.

3.2.1 Different amount of time used for manipulating apparatus and doing measurements

In all three case studies with traditional labs in university courses with and without computer (GE 1 - 3, table 1 and 2) the biggest part of labtime is used for two classical categories, to build up the apparatus (MA or CMA) and to do measurements (ME or CME). These two classical activities of labwork together take between 20 and 80% of labtime, perhaps sometimes less in computer labs. This indicates, that there is a large variety of different labwork approaches with respect to the amount of time used for manipulating apparatus and doing measurements. Labs of a typical traditional type at German universities (GE1 in Fig 1 and 2) tend to have more time in MA and ME (about 80%) and less interaction with the tutor (3.P), whereas in other labs in GE2 and GE3 (Fig 3 and 4) we see only about 50% of time in MA and ME, and more interaction with the tutor.

Table 1: Time budget of lab contexts in % of labtime in different types of lab, **without** computer

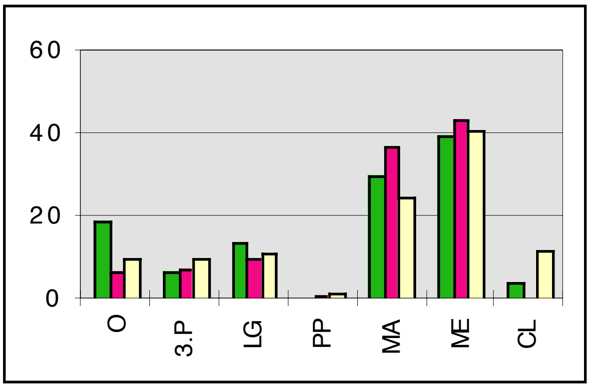


Figure 1: Three different groups in lab 3 in GE1

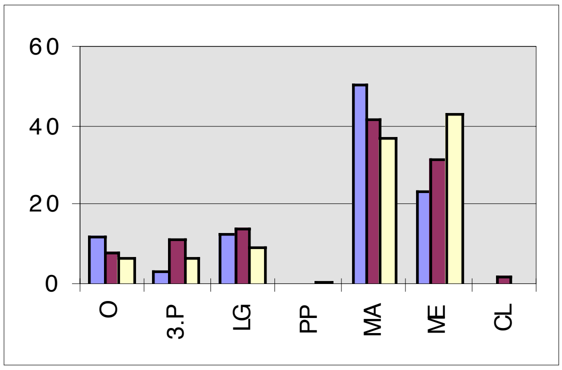


Figure 2: Three different labs in group 2 in GE1

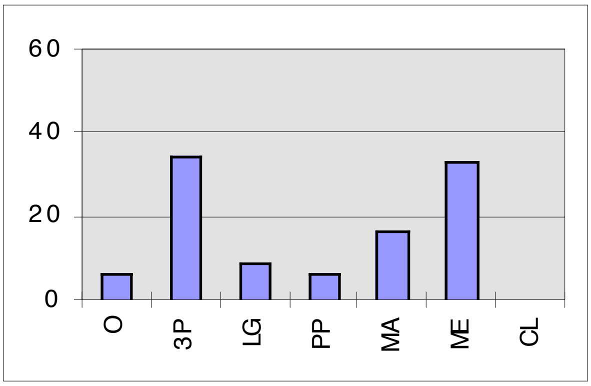


Figure 3: One lab in GE2

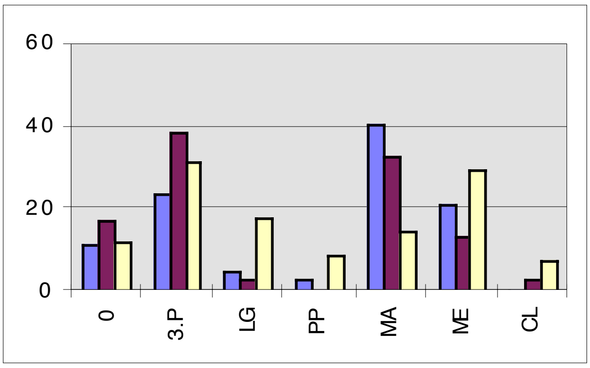


Figure 4: Three different labs in one group in GE3

Categories for context

3.P = talking with a third person (tutor/student);
LG = using the labguide;
PP = working with paper and pencil
MA = manipulating apparatus;
ME = doing measurements;
CL = doing calculations

There is also evidence, that labwork approaches differ a lot in the relation between MA and ME. Some of the experiments (Fig 2 and 4) take a lot of time to set-up the apparatus (MA up to 50%) and less time for measurement (ME about 20%), others need little time for setting up the apparatus (MA 15% of labtime) and need more time for measurement (ME up to 40% of labtime). Of course, these numbers are depending on how far the set-up is prepared before students come to the lab, how many problems occurred, and how many or what kind of measurements are required in the labguide.

Table 2: Time budget of lab contexts in % of labtime: students use different resources in different types of lab, **with** computer

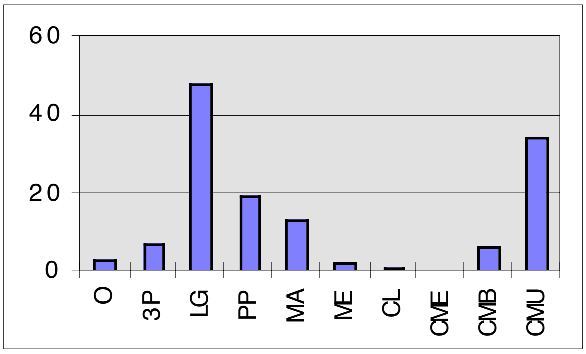


Figure 5: Averages of a whole teaching sequence with one student in FC1

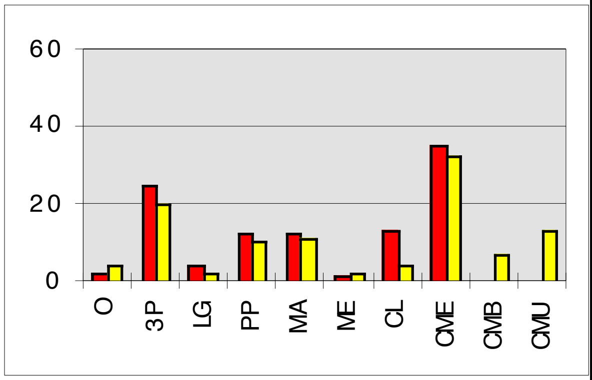


Figure 6: Two labs with two different groups in GE2, one with MBL, one with MBL+MBS

Categories for context

3.P = talking with a third person (tutor/student);
LG = using the labguide;
PP = working with paper and pencil;
MA = manipulating apparatus;
ME = doing measurements;
CL = doing calculations;
CMA = manipulating apparatus with computer;
CME = doing measurement with computer;
CMB = doing model building with computer;
CMU = using an already built model

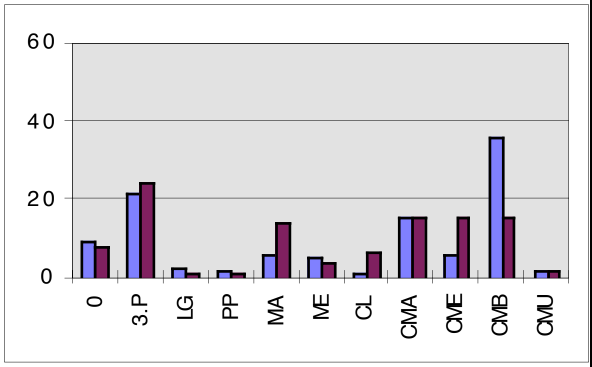


Figure 7: Two different labs in one group in GE3

3.2.2 Manipulating apparatus and doing measurements with and without computer

Without computer we have MA and ME, with computer we have MA, ME, CMA and CME. So, in labs with integrated use of computer, the time has to be shared between more resources. Nevertheless, if we compare labs with and without computer in GE2 and GE3, the total time for manipulating apparatus and doing measurements in labs with computer (MA+ME+CMA+CME) is not more than in labs without computer, it even tends to be less. This might be due to two effects, first that labs with integrated use of computer are more innovative and therefore being prepared and guided more carefully, second that taking measurements with computer often is faster than without. There seems to be a tendency also, that in labs with integrated use of the computer, more time is devoted to activities with computer (CME and CMA) than to classical activities without, such as MA and ME (see Fig 6 and 7).

In the special case of FC1 (Fig 5), the computer is not at all used for measurements, only for modelling, so the time devoted for CME is zero, and the time devoted for MA and ME is also small (about 20%). This indicates a totally different approach of integrating the computer into labwork: more time for guidance by the teacher ("lab course"), more time for using computer models adapted in parallel to the experiment. The particular kind of experiments in geometrical optics must also be taken into account : it implies more qualitative observations and very simple and fast measurements (mainly lengths).

3.2.3 Different amount of time offered by the tutor or teacher

Important differences are shown with respect to the role of the tutor or teacher. Whereas in GE1 the time spent together with the tutor and other students (3.P) is only about 10%, in GE2 and GE3 we have between 20% and 40% of labtime spent mainly with the tutor. In the case of FC1 (Fig 5), the teacher gives a lot of guidance by oral instructions, which here was coded as LG and takes nearly 50% of labtime. Here, the teacher works as a labguide. So with respect to the role of the teacher or tutor we have three different forms: In GE1 there is a "normal" tutor responsible for about 6 to 8 groups working in parallel; in GE2 and GE3 the tutor (who is also the researcher) is responsible for the videotaped groups only and therefore offers more time from his side to interact with and talk to the students; in FC1, we have a form of a "lab course", in which the teacher gives instructions during the lab activities. This is due to the special teaching structure of this kind of lab in upper secondary school in France: lecture and labwork are integrated.

3.2.4 Low tendency to analyse data during labwork

In all labs, very little time is used for calculations (CL). Together with later results about verbalisations of mathematical knowledge (KM), and together with qualitative observations this indicates that activities like qualitative checks or doing rough calculations to compare theory with measurement are very rarely done (between 0% and 10% of labtime). We do not think of long calculations here as being especially fruitful for to link theory to practice; rather we believe that qualitative predictions and rough fast calculations during labwork are fruitful. The categories for calculator (CL) and paper and pencil (PP) were used in very limited amount of time (below 5% of labtime). The highest values are found in Fig 1 for group 3 and in Fig 6 for lab 1. The high value in Fig 1 for group 3 indicates, that some students tend to do more calculation "by their own" than other students under the same conditions. So different students might have a varying tendency to do quantitative checks of the data. The high value for lab 1 in Fig 6 is due to the fact, that in this case of integrated use of the computer, a special software ("Origin") was offered to do calculations from measurements taken with the computer interface (MBL). All findings together indicate, that data analysis often is not an important part of labwork. These results would also be in line with the assumption, that students mainly aim at "gathering data" and not at "reflecting theoretically" which can be seen as one way "to link theory to practice".

3.2.5 Working with the labguide often takes little time

Working with the labguide in "normal" labs is going on in about 10% of labtime or less in all 3 German case studies at university level (GE 1-3), except one lab in GE3 which is due to special demands of the labguide in this special lab. In average, it is the third often used resource in these labwork sessions. The differences are explainable by the different kind of guidance and different length of labguides. Some impose a quite guided structure of labwork sessions which includes all tasks and suggestions the students need for doing the experiment ("cookbook style"). The high values for LG in FC1 (Fig 5) were discussed already in 3.2.3.

3.2.6 Comparing different groups of students doing the same lab

In Fig 1, three different groups are analysed with the same lab. It is interesting to see that the time for measurement is more or less equal (according to the requirements of the labguide), whereas the time for set-up varies between about 25% and 35% of labtime. The special value for CL has been already discussed in 3.2.5

3.2.7 New time structure of activities in labs with computer

Table 2 gives the time budget of the use of different labwork contexts in labs with integrated use of computer. A first look immediately shows that labs with integrated use of computer have a greater variety of different contexts and resources that are used. Additional four resources (CMA, CME, CMB, CMU) had to be defined. According to the different approach of integrating the computer into the lab activities, not all of these four resources were used in each case. In FC1 (Fig 5), we have only model building (CMB) and model use (CMU) with the computer. In GE2 (Fig 6), we have lab 1 with MBL only, that means category CME only, whereas in lab 2 the computer is used for measurement (MBL) and model building (MBS), that means categories CME, CMB and CMU. In GE3 (Fig 7), we have MBL and MBS used in both labs, that means all four contexts CMA, CME, CMB, CMU.

In general, our impression is that the computer can be used in a way that less time is spent on doing measurements, and this time is used to build up the additional computer set-up and doing additional activities, for instance calculations with the computer or model building and model use with the computer. The time used for measurement with the computer varies from 5% (Fig 7) to 35% (Fig 6). We assume, that normally measurements with the computer will take less time than without computer, this would mean in the order of 10%. In some cases the technique and software for taking measurements with computer has to be learned first. In other cases more time is needed due to the special experiment, e.g. in the "Pohl's wheel" experiment, the time needed for measurement is determined by the experimental procedure itself. For both reasons the amount of time can rise to about 40%.

3.2.8 Computer model building and model use integrated into lab activities

When model building with STELLA (CMB) is used during labwork (GE2 and GE3), model building with the computer takes about the same amount of time as manipulating (MA) or measuring (ME). In these labs model building takes time between 5% and 35% of labtime, whereas the time for model use (CMU) is below 15%. The integration of model building into labwork activities for us is an important contribution to link theory to practice if model building is done immediately in the labwork context. From this point of view it is important to see that model building can take up to about 35% of labtime, but it seems to be less time in other cases, perhaps due to getting familiar with the tool.

All this makes sense in a way that integrating computer measurement and computer model building into the lab seems to be realistic after some time which is needed for learning to use the computer tools. It often saves time for measurement which can be used for handling the computer, to do model building, and to link measurements and theory.

3.2.9 Time spent with computer can exceed time spent with real experiment

In all three case studies with computer the time for computer activities (CMA; CME; CMB and CMU) exceeds the time used for classical activities MA and ME (Fig 5-7). This fact may be surprising, and perhaps disappointing. It is one of the well known arguments against using the computer for labwork. On the other hand - as we will show in section 3.4 - the contribution of classical activities like MA and ME to talking about physics and thereby to link theory to practice in many cases is lower than with some of the computer activities. If these are integrated into lab work, they always take place in the context of the real apparatus. In some cases, using the model first allows the students to understand more quickly what they have to do during an experiment, which takes thus a shorter time.

3.3 The time budget of knowledge verbalisation in different types of labwork

In this paragraph results about the amount of time used for verbalisation of different types of knowledge during labwork are shown.

3.3.1 Different amount of time for knowledge verbalisation in different labs

In table 3 and 4 we see an overview of knowledge verbalisation during labwork in labs with and without a computer. The total amount of knowledge verbalisation (SumK) varies between about 15% of labtime and about 45% of labtime. This is a rather big variance, and the smaller values indicate a general problem with some labs: the tendency to verbalise knowledge connected with activities during labwork in some cases is rather small. It might be important to analyse the factors which influence it. Drawing on later results in section 3.4 we assume, that interaction with the tutor (3.P) and modelling with the computer increase knowledge verbalisation. Therefore, the relatively small numbers for SumK in GE1 (Fig 8 and 9) might be due to less interaction with the tutor and not using a computer for modelling. The higher numbers for SumK in GE2 and GE3 are then due to the contrary, both more interaction with the tutor (Fig 10, 11) and/or use of the computer for modelling (Fig 13, 14).

Table 3: Time budget for verbalising different types of knowledge in % of labtime: "profile of detected knowledge" in different types of lab, **without** computer

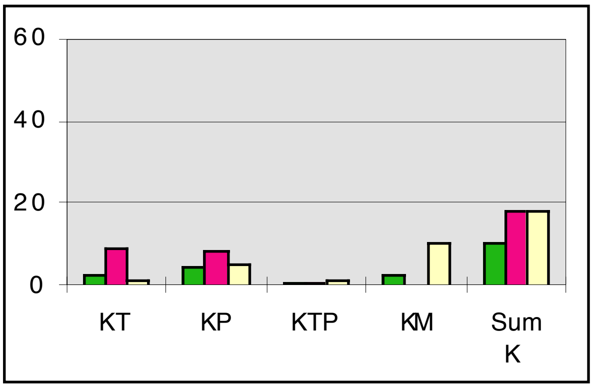


Figure 8: Three different groups in lab 3 in GE1

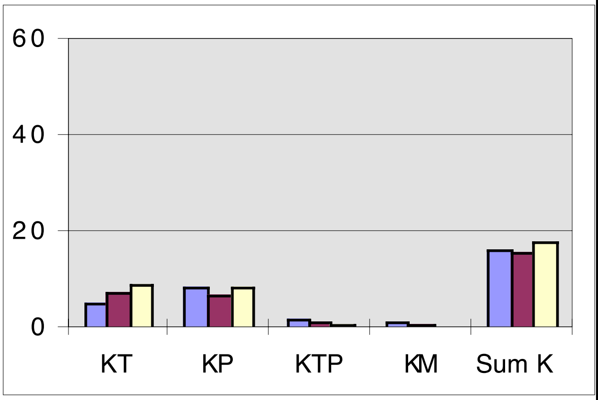


Figure 9: Three different labs in group 2 in GE1

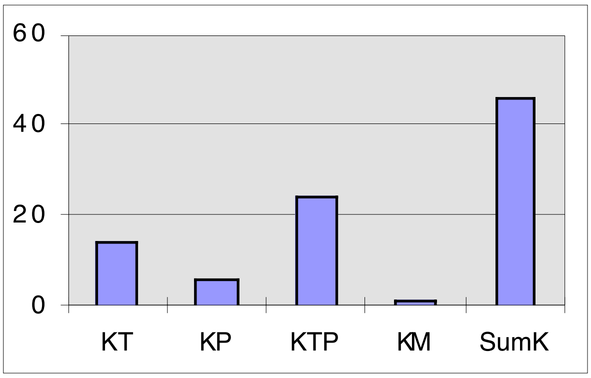


Figure 10: One lab in GE2

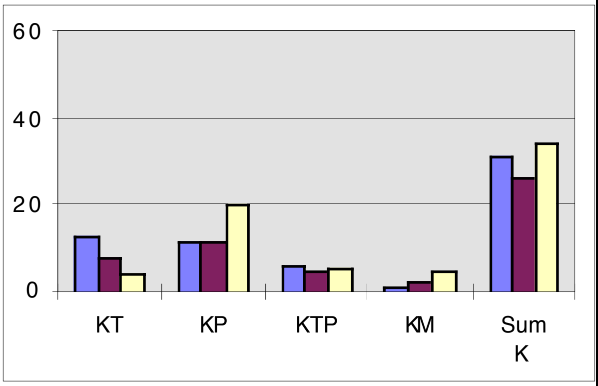


Figure 11: Three different labs in one group in GE3

Categories for verbalised knowledge

KT: Technical knowledge

KP: Physics knowledge

KTP: Physics knowledge related to objects of the real world (FC1, GE2)

KTP': Physics knowledge combined with technical knowledge (GE1, GE3)

KM: Mathematical knowledge

SumK: The sum of all types of knowledge

The high value of SumK in FC1 (Fig 12) might have the same reasons, and in addition a more extensive use of the category KT and some additional categories, as said before, relative to the use of the materialised model. Here, the most important single category with computer is KMM (nearly 20% of labtime); we must remember that in this category the student talks about the geometrical objects on the screen of the computer themselves, without giving them a physical meaning; its weight is caused by the necessity for students to learn the handling of the software, which they had never used before; this point is discussed below in more detail.

The categories KTP and KMT, which could indicate mainly the link between the world of objects/events and the world of physics ideas are much less represented (about 10% of labtime).

Table 4: Time budget for verbalising different types of knowledge in % of labtime: "profile of detected knowledge" in different types of lab, **with** computer

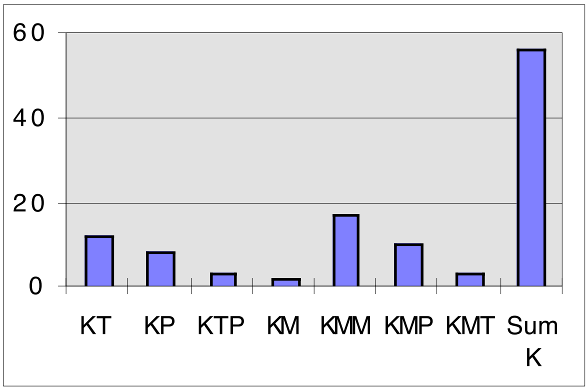


Figure 12: Averages of a whole teaching sequence with one student in FC1

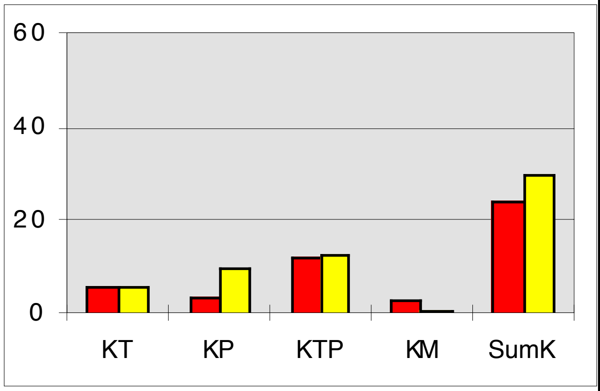


Figure 13: Two different labs with two different groups in GE2, one with MBL, one with MBL+MBS

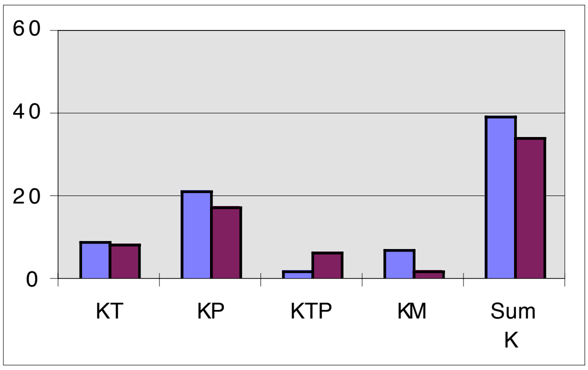


Figure 14: Two different labs in one group in GE3

Categories for verbalised knowledge
KT. Technical knowledge
KP: Physics knowledge
KTP: Physics knowledge related to objects of the real world (GE, FC1)
KTP': Physics knowledge combined with technical knowledge (GE2, GE3)
KM: Mathematical knowledge
SumK: The sum of all types of knowledge
KMM, KMP, KMT: Corresponding categories with materialised model on the screen

3.3.2 Time used for talking about physics in different labs

The categories KP, KTP (and KMP in FC1) best represent the amount of talking physics during labwork. The percentage of labtime here varies between about 10% and about 30% of labtime. Again, these numbers are higher in GE2 and GE3 than in GE1, probably due to the same reasons as discussed in 3.3.1. So, it is important to be aware of the significant role of tutors during labwork and of the additional chance coming from modelling with the computer.

In GE2, the category KTP is used when verbalisations show a link between physics and apparatus. Here, in all three types of labwork (with and without computer, Fig 10 and 13) this link was seen in about half of all knowledge verbalisations (in about 10% to 25% of labtime). This seems to be higher in a lab without computer (25%, Fig 10) than in two labs with computer (about 10%, Fig 13). This could be interpreted that to link theory to practice as an objective in some cases might be fostered better in labs without computer. But we should keep in mind, that it were different groups of students in Fig 10 and Fig 13.

3.3.3 Rare verbalisation of mathematical knowledge

Statements about mathematical knowledge (KM) were detected very rare, they were found only in less than 5% of labtime. This together with a similar finding in 3.1 about the rare use of calculators (CL) indicates that an important link between theory and practice during labwork is missing. Again, group 3 in GE1 (Fig 8) shows a higher value.

3.3.4 Knowledge verbalisation in labs with computer

In table 4, the amount of knowledge verbalisation in labs with integrated use of computer in FC1, GE2 and GE3 is shown. If we look at the sum of all knowledge verbalisations (SumK) this percentage of labtime varies between 20% and over 50%. The sum of KP and KTP alone is in all three case studies around 20%. If we compare GE2 and GE3 with and without computer, we see no clear difference. So, the effects of the use of computers have to be analysed in more detail in section 3.4.

3.3.5 Different groups show different tendencies to verbalise knowledge

The analysis of the same labwork session with three different groups of students (in Fig 8) indicates, that the amount of knowledge verbalisation can be very different for different groups in the same lab. The amount of verbalisation of knowledge is depending to a high degree on an individual tendency of groups to talk. Group 1 in Fig 8 is obviously a group talking about knowledge much less than other groups. We have the hypothesis that this is the reason for higher amount of verbalisation of knowledge in the traditional group in GE2 also (see Fig 9).

3.4 How different labwork contexts contribute to the verbalisation of physics knowledge - a tracer for physics learning

We define a new variable "density of knowledge verbalisation in a special lab context" to have an indicator for how much a special lab context contributes to knowledge verbalisation and thus potentially to physics learning. We are especially interested in the verbalisation of physics knowledge as a contribution to the objective "to link theory to practice", and therefore we calculated densities of the knowledge categories KP and KTP and added both of them in the diagrams.

The density of verbalisation of physics knowledge in different resources X is calculated by first looking to all time units where students work with one resource X, e.g. labguides (LG). The number of time units in this resource X is counted. Then the number of time units with verbalisation of physics knowledge (KP) when using this resource X is detected also and is counted. The ratio of the number of time units with KP divided by the total number of time units in this resource X (multiplied by 100) then results in what we call the density.

In GE1 to 3, the following definition of density of verbalisation of knowledge KP in resource X is used:

$$Density(KP/X) = 100 \cdot \frac{\sum TimeunitsKPinX}{\sum allTimeunitsX}$$

A slightly different way of establishing some correlation between some resources and expressed knowledge is used in FC1. Here, six new variables C1 to C6 are defined in the Excel worksheet with the following formulas:

	New variable for knowledge	Type of know-ledge	Description of meaning
Expe ri ment	C1 : ((MA+ME)*KT) C2 : ((MA+ME)*KP) C3 : ((MA+ME)*KTP)	KT KP KTP	Talking about world of objects Talking about physics concepts Link real world objects/physics concepts
Com pu ter	C4 : ((CMB+CMU)*KMM) C5 : ((CMB+CMU)*KMP) C6 : ((CMB+CMU)*KMT)	KMM KMP KMT	Talking about objects on the screen Link objects on the screen/physics concepts Link objects screen/objects experiment

The first three columns are filled with 1 if the student, while experimenting (MA, ME), expresses a knowledge about real objects and events (KT), about concepts (KP) or about relations between objects/events and physics concepts (KTP). The last three ones correspond to the case where the student, while using the computer-based model (CMB, CMU), expresses a knowledge about the software or the geometrical entities he sees on the computer screen (KMM), an interpretation of what he sees on the screen in terms of physics (KMP) or a relation between what he sees on the screen and what has been observed in the world of objects (KMT).

Finally, to find an expression which shows the correlation between contexts and verbalisation of certain knowledge, FC1 uses a similar kind of "density of verbalisation" as in the German case studies. More mathematically it can be written, for the two first columns corresponding to each two types of resources :

$$C1/EXP = \frac{\sum (MA + ME) * KT}{\sum (MA + ME)} \quad \text{and} \quad C4/COMP = \frac{\sum (MB + MU) * KMM}{\sum (MB + MU)}$$

This way to establish a correlation between the students' use of the resources of the situations (left side of the grid) and the knowledge (right side of the grid) has several consequences we must emphasise : students have four great kind of resources to their disposition : what the teacher says to the whole class, the paper when they write an answer or draw a schema, the experimental device and the computer; we choose to focus only upon the experimental device (MA+ME) and the computer (CMB+CMU) in order to compare them; by adding MA and ME (or CMB and CMU), we make no difference between those categories, considering for our purpose a global activity of experimenting (respectively using the computer-based representation).

In Table 5 and 6, only resources which lasted at least 15 minutes (30 time units) out of one lab session (1.5 to 3 hours) were used. All the shorter resources were not taken for calculating densities. Table 5 displays the density of verbalisation of physics knowledge in different labs without computer. This density indicates whether in one context the tendency towards verbalisation of physics knowledge is rather high or rather low.

3.4.1 Manipulating apparatus and doing measurements tends to contribute little to talking about physics

In figures 15 - 21 from all four case studies with and without computer in altogether more than 15 different lab sessions we see that the density of verbalisation of physics knowledge is rather low while manipulating apparatus (MA, CMA) and doing measurements (ME, CME) or both together in the FC1 category EXP. In only less than 20% of the time working with these contexts, students are talking about physics. So the activities with the highest amount of labtime have a rather low contribution to talking about physics, and from this result we expect a small contribution of these activities to the objective "to link theory to practice". Especially, we see that the density of talking about physics knowledge in labwork without computers is least while doing measurements (ME, Fig 15-18).

It is worth noting, that doing measurements with computer (CME in Fig 19 and 20) is not better in this respect, but as we know from section 3.2, it can take less time. This is true e.g. in GE3 (lab 4), but not in GE2, because the time there is determine by slow processes in the experiment itself to come to a stable state of oscillations of Pohl's wheel.

3.4.2 Some promising cases of talking physics while manipulating apparatus and doing measurements

The best values of densities near 20% in ME and MA should be analysed in more detail. The highest density of KP and KTP while doing measurements (20%) is found in lab 1 in GE3 (Fig 18), where students where asked in a rather simple but rather open task to determine velocity on an air track with one or two light gates with different methods. The same lab has also an acceptable density of about 15% while manipulating apparatus (MA).

A similar rather high density of verbalising physics knowledge during manipulating apparatus and doing measurements is found in FC1 with nearly 20% (Fig 21 with the category EXP=MA+ME). The interesting fact here is, that relating physics knowledge to objects of the real world (KTP) here is larger, while talking about physics alone (KP) is less. From a more detailed analysis of this case study (see Working Paper 7) we know, that in some of the situations this high density can be explained by the fact, that the computer model is used before doing the experiment. We see in the same figure (Fig 21), that the relation between KP (in fact KMP) and KTP (in fact KMT) is just the opposite while using a computer (COMP).

Table 5: Density of verbalisation of physics knowledge (KP+KTP)
in different lab resources in % (labs **without** computer)

(or =KP =KTP)

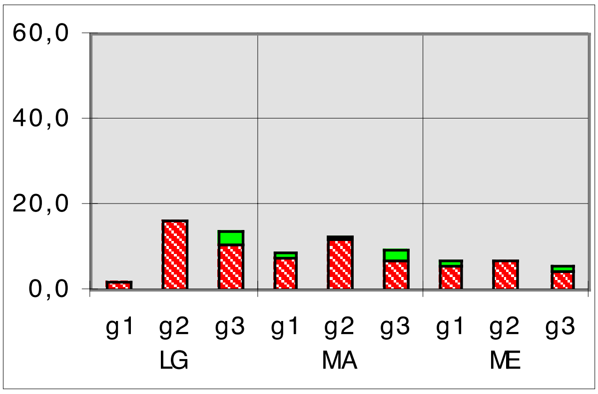


Figure 15: Three different groups g1, g2 and g3 in lab 3 in GE1

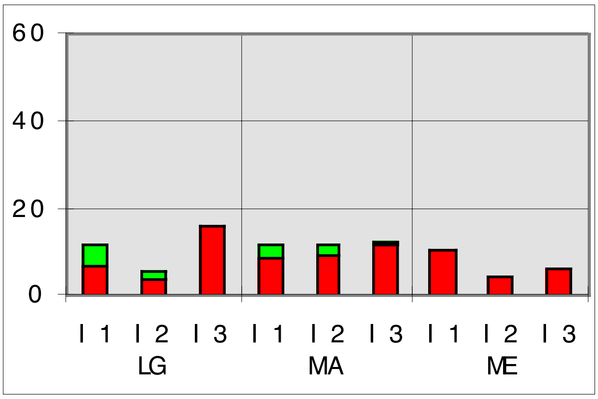


Figure 16: Three different labs l1, l2 and l3 in group 2 in GE1

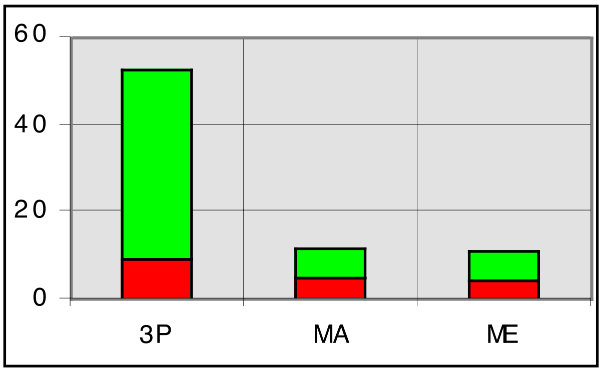


Figure 17: One lab in GE2

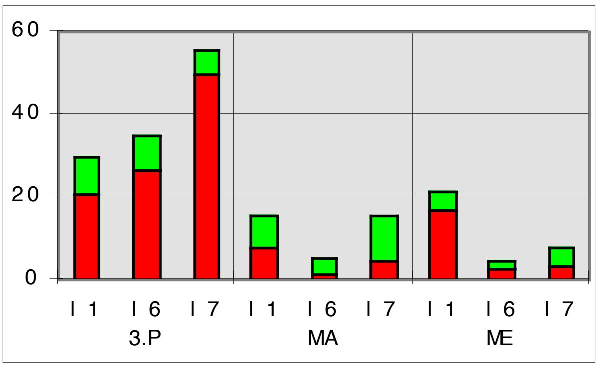


Figure 18: Three different labs l1, l2 and l3 in one group in GE3

That means: physics concepts are more likely to be used while working with the computer than while doing the real experiment. So, it might be an important conclusion that to start an experiment with a computer simulation before doing the real experiment may help students to associate the physics concepts to the world of objects and events, verbalising the concepts when using the computer, and linking them to the objects during the experiment. A similar rather high density of verbalising physics knowledge during manipulating apparatus (MA) and doing computer measurements (CME) is found in GE3 in lab 5 (Fig 20). In this lab, oscillations of a spring were analysed with the computer. The interpretation of these facts is not finished; the rather high density values might be due to a combination of factors like being not too complex, but still demanding..

Table 6: Density of verbalisation of physics knowledge (KP+KTP) in %, in different lab resources (labs **with** computer)

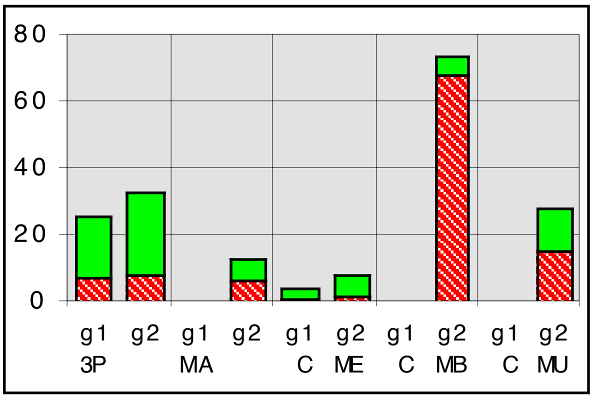


Figure 19: Two different labs with two different groups in GE2, one with MBL, one with MBL+MBS

=KP; =KTP

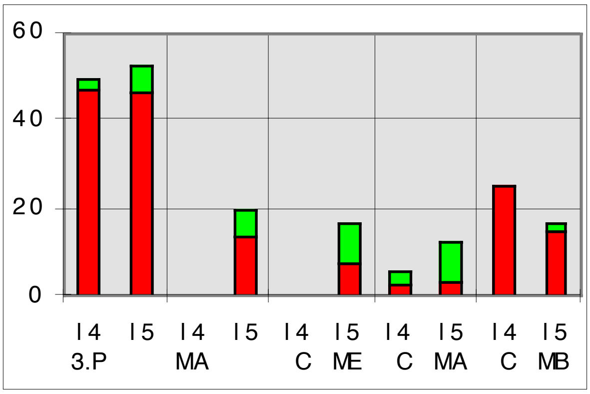


Figure 20: Two different labs in one group in GE3

=KP; =KTP

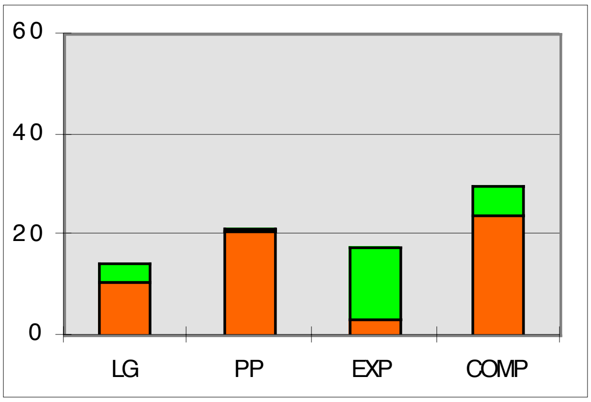
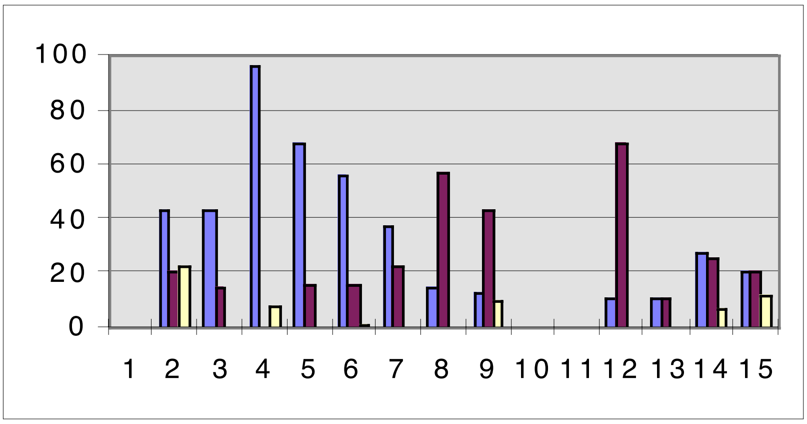


Figure 21: Average of different labs, one student (FC1)

KTP/ KMT
KP/ KMP

EXP=MA+ME
COMP=CMB+CMU

KTP, KP in context EXP,
KMT, KMP in context COMP



KMM /COMP : description of the objects on the screen (C4)

KMP/COMP : link objects on the screen to physical concepts (C5)

KMT/COMP : link objects on the screen to objects in the experiment (C6)

Figure 22: Density of KMM, KMP and KMT in different labs over time when using a computer (FC1)

So, in general the contribution of manipulating apparatus and doing measurements to physics learning is expected to be low, if not special care is taken to improve the link between theory and practice, e.g. by pushing students to find out a measurement procedure according theory, or to do predictions or rough calculations during measurements.

3.4.3 Working with the tutor tends to contribute most to talking about physics

In chapters 3.2 we already saw a big difference between GE1 on the one hand and GE2 and GE3 on the other in the time students worked with the tutor (about 10% of labtime in GE1 and more than 20% GE2 and GE3). Now we see, that this might be important: Talking with a third person (mainly the tutor) in all types of labwork with and without computer has the highest density of verbalisation of knowledge (Fig 17-20). This was found in GE2 and GE3. It was not found in GE1 and FC1. In Fig 15, 16 and 21, this value is missing, because working with the tutor in these cases was done over less than 15 minutes in the analysed labs, so the density could not be determined in a reliable way. In labs without computer (Fig 17 and 18) the density of talking physics ranges from 10% to nearly 50% of time working with the tutor, in labs with computer (Fig 20 and 21) it is about the same.

It is worth noting, that in FC1 we have the special case of a "lab course", where in nearly 50% of time a lot of guidance is given by oral instructions of the teacher, coded as LG. We see in Fig 21, that the contribution of this context LG to the talking of physics of the one analysed student out of a whole class is smaller than with interactions of a tutor in other labs, where typically only 2 or 3 students are interacting. This is quite natural, because the students obviously speak less when the teacher is talking to the whole class than when they are interacting with a tutor.

This rather high density of verbalising physics knowledge while interacting with the tutor in GE2 and GE3 compared to the results in GE1 might be explained by the special role of the tutor in these case studies: he was also the researcher and he asked many questions concerning the experiment. If we assume that an increase of knowledge verbalisation during labwork is a contribution to better physics learning during labwork, this fact might be of some importance. As the total amount of time used for verbalisation of physics knowledge still is rather low, this result leads to a recommendation to improve the role of the tutor in this direction. For instance, he can ask students to predict values or to calculate expected values from theory and compare them to their own measurement.

3.4.4 Working with the labguide can contribute to talk about physics

The contribution of working with the labguide to talking about physics shows different percentages with different groups and different labguides (between 5 and 15% in Fig 15, 16 and 21). The highest value of about 15% is reached in one lab in GE1 (Fig 15 and 16, lab 3 in group 2). In this lab the labguide was changed by adding questions about physics concepts and by tasks to do predictions and rough calculations. So the results show again the important role of the labguide to improve talking about physics and learning during labwork. The same value of about 15% is reached for working with the labguide in FC1 (Fig 21). This is also due to special kind of tasks and questions in this case study, which are more qualitative and asking some reflection to the students. This result is given further evidence by rather high values of density while working with paper and pencil (Fig 21). Group 1 in Fig 15 shows a very low density, this group obviously has a lower individual tendency to talk about physics, as we saw already in section 3.3.

3.4.5 Working with model building tends to have the highest density of talking about physics

In table 6 we see results about density of verbalising physics knowledge in labs with integrated use of computer. The most striking effect is the high tendency of talking physics while building a model with STELLA (CMB). In GE2 (Fig 19) we find a density of about 70%, in GE3 (Fig 20) we find about 20%. The big difference might be due to a specially gifted and motivated group of students (g2) observed in this experiment in GE2. The part of KTP is small compared with KP, which at least in GE2 can be interpreted as a lower tendency during model building to connect physics explicitly to the real world. In Fig 21 we can observe similar results from FC1. Again, the most striking effect is a high density to talk about links between objects on the screen and physics concepts (KMP), whereas the tendency to relate objects on the screen to objects of the real world (KMT) is much lower. The average density of talking physics while working with the computer model (KMT + KTP) here is found with nearly 30%. So, working with a computer model during labwork increases the probability to talk about physics in all cases, in some cases even to a high extent (70% of labtime working with model building). On the other hand, the connection of physics to the real world often is not done explicitly to a large extent. Some researchers nevertheless believe, that talking about physics in the presence of the real experiment always might contribute to the link of theory to practice. But this is not confirmed by our results.

3.4.6 Learning to use the software

In Fig 22, we show a different type of diagram, which displays densities of three different types over time, observed in FC1 all along the teaching sequence, that is, during eight sessions of two hours. For the first category (talking about objects on the screen and software problems, KMM, we observe a decreasing density over time. This means, that later situations need less talking about the difficulties that the students encounter in handling the software. This can be seen as an effect of learning to use the software. On the other hand this diagram shows, that the density of talking physics while working with the computer model (KMP) can go up to 70%, and the tendency of making connections to the real world (KMT) is low in all the different labs. See also section 3.4.5 above.

4 Effectiveness of labwork aiming at "to link theory to practice" - generalising results

4.1 About the effectiveness of doing measurements

All our data about the lab context "doing measurements (ME)" tell us two things: On the one hand this activity very often takes a large amount of time in labwork, typically about 20 - 50% (see Table 1). On the other hand the probability to talk about physics during measurements is rather low (in most cases below 10%). This means, doing measurements does not contribute a lot to link theory to practice during labwork. The consequence of this could be:

- reduce the time for measurements (for instance by using computer measurements)
- combine doing measurements with making predictions or theoretical analysis of the data or ask questions by the tutors or in the labguide during the process of doing measurements
- include analysis of data and rough calculations into the measurement process.

If the learning of experimental skills should be improved, it would be more effective to pay attention on the periods of manipulating apparatus. In this context the most technical knowledge is verbalised.

4.2 A missing link - low tendency to analyse data during labwork

In most of the analysed labwork we find a low part of time devoted to doing calculations and using mathematical knowledge (see Tables 1 - 4). If we see these activities as possibilities to link theory to practice during labwork, the amount of time devoted to this kind of activities should be increased, for instance by asking students to make qualitative observations or predictions or rough calculations related to their measurements during labwork by the labguide or the tutor. We do not think of long calculations here as being especially fruitful for to link theory to practice; rather we believe that qualitative checks or predictions and fast rough calculations during labwork are important.

4.3 Positive effects from more engagement of tutors

In three of our case studies (FC1, GE2, GE3) there is a high engagement of the tutor or teacher, and they offered a lot of time interactions with students. The amount of time for working with the tutor (category 3.P or LG in FC1) ranges from 20% to 40% of labtime. To the contrary, in a more traditional lab (GE1) the time for working with the tutor ranges from 5% to 10% of labtime (see Tables 1 and 2). Now, if we look to the Tables 5 and 6, we see that working with the tutor in many cases has a high probability for talking about physics (up to 45% of time spent with the tutor). Consequences and recommendations from these findings might be:

- train the tutor to be ready to talk about physics of the lab with the students and perhaps do feedback about lab reports at other times.
- Perhaps there could be improvements in the same directions if one group of students has to report to another group of students what they have done.

More engagement and available time of the tutors contributes a lot to verbalisation of physics knowledge during labwork.

4.4 Positive effects by changing a labguide

In the case study GE1, a traditional labguide is changed by introducing some tasks and questions concerning to talk about the physics concepts in this lab. This is done in lab 3. Now, if the look to Table 5, Fig 18 and 19 we clearly see the effect in the density of talking physics in this lab during working with the labguide: While in the other labs the probability of talking physics during working with the labguide is below 10% of time working with the labguide, this probability raised to about 15% in lab 3 with the new labguide. This gives additional evidence that there is a chance to improve labwork by including special tasks like talking about concepts, making predictions and doing calculations during labwork.

4.5 Is it realistic to use a computer integrated into labwork?

Related to the use of computer during labwork we had three different cases: labs without computer (in GE1), labs with using the computer only for data collection (GE2), labs using the computer only for modelling and simulations (FC1) and labs using the computer for data collection and model building (GE2, GE3). From an overall view of looking to Table 2 about time budgets in labs with computer we see that the time is distributed in a new way between more types of activities. This seems realistic, at least after some time for learning to use the computer tools. In some cases, however, the time needed for measurement is the same for traditional measurements and computer-based measurement (compare results from GE2 in Fig 7). In this case, it is an experiment about Pohl's wheel and doing measurement with the computer could not save time for doing the measurement, because both the amplitude and the phase had to be measured in the oscillation diagram on the screen.

4.6 Effects of using a computer for measurements and data analysis

In GE2, one version of the lab with Pohl's wheel is done with using the computer for data collection (CASSY) and data analysis (Origin). If we look to Table 2 (Fig 6) this type of lab is marked with "MBL". We see that this type of lab has a higher amount of time devoted to calculations (with data analysing software "Origin") and corresponding to this in Table 4 (Fig 13) we see the increase of use of mathematical knowledge for this type of labwork, too. But this use of mathematical knowledge still is rather low (below 5% of labtime). On the other hand, with this type of lab we see (from the same Fig) a lower amount of using physics knowledge than in other types of labwork. These findings may warn us, that the use of computers not immediately and by itself results in better learning of physics.

4.7 Effects of using a computer for model building

The building of a computer model for a special lab takes considerable time (between 10% and 35% of labtime). From Fig 7 we see a tendency that this time used for model building can be decreased after some application of the software used for model building (STELLA). On the other hand, we see from Table 6 that in both case studies GE2 and GE3, where model building is used integrated into the laboratory work, the density of use of physics knowledge is rather high during model building activities (CMB). The same effect is found in FC1 with model use (CMU), which in that case has similar features as model building, e.g. to adapt the simulation to the real experiment (see Fig 21). We find densities for the use of physics knowledge during modelling activities of about 15%, 25%, 30% and up to 70%. This effect is predicted by earlier investigations (Schecker 1991) and is an important rationale for integrating model building into the lab activities. On the other hand there are also negative findings, especially from case studies FC1 and GE2. They found that relating physics knowledge to real objects (KTP, KMT) does not happen very often during model building (see Table 6, Fig 19 and 21).

The use of model building systems like STELLA can improve the effectiveness of labwork related to the link of theory and practice by supporting the use of physics concepts. But this does <u>not</u> a priori guaranty a better link of theory and practice. To reach this the MBS has to be carefully implemented and attention has to be paid to the kind and extend in which the physics model is used and applied to the experiment. This part of the simulation process seems to be more effective concerning the link of theory and practice. Furthermore, to make modelling effective it is important to discuss explicitly the model with the students in order to foster the link to the experiment.

4.8 Summarising Recommendations

The remarks and conclusions above authorise to put forward a certain number of recommendations for more efficient labwork in science education :

- training of tutors to enable them to guide students towards a better link of theory and practice, e.g. by asking them to compare their own measurements with results of rough theoretical calculations, should be seen as a promising way to increase effectiveness of labwork with this objective in mind.
- the improvement of lab guides should include appropriate questions to foster students' awareness of theory during labwork.
- the loose of time/energy/motivation and the mental confusion for students due to the use of an unknown software should be avoided as far as possible. This can be achieved by using the same software (STELLA, Cabri-géomètre) in several subjects or domains as a tool.
- modelling activities such as those shown in these studies can facilitate the understanding of physics by students; they should play a greater part of computer use in science education, which should not be restricted to data acquisition and computation;
- modelling activities have to be carefully embedded in appropriated instructions that prompt learners to verbalise their knowledge; they can be a very powerful tool in situations implying predictions, performance of the experiment, discussion and formulation of findings in comparison with predictions;

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ANNEX 1

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

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

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

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

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

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

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

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

- During labwork there should be a constant interplay between the ***collection of data*** (observations, measurements etc.) and theory. During the project, the place of measurement was increasingly questioned. If measurement is undertaken as an activity, it should be carefully 'targeted': clear objectives for the activity should be set, and consideration should be given to other activities that might follow on from measurement such as data processing, the evaluation of theories, drawing conclusions and evaluating experimental techniques and apparatus.

Obviously, computers and sensors can play an important role in saving time during these tasks and in some cases it is only possible to make measurements with the aid of computers. But, the significance of the measurement must be addressed directly in teaching and not hidden behind routines.

- ***Data processing and the development of conclusions*** provide opportunities for the development of conceptual and epistemological understanding by students. Our work underlines the very different choices that can be made by teachers. Data processing can be treated as an algorithm, or alternatively can be treated as an opportunity to teach about one of the most important aspects of epistemology: the confidence that can be attributed to data and the uses to which data can be put.
- The development of ***epistemological knowledge*** is rarely addressed in most countries, and in countries where it is addressed, labwork is not the teaching method used. There are opportunities in labwork to promote a reflection on the part of students upon links between theory and data. One approach involves addressing experimental design. Another approach involves the selection of real situations from ongoing research, addressing how the research was operationalised and the main issues addressed during the work as it proceeded.

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

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

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

With this choice, it becomes necessary to organise students' overall programme of labwork activities within a coherent long-term programme and this assumes that the types of labwork undertaken by students should be varied. For example, selected part of the whole experimental process, studies of identified cases encountered in labs to teach images of science, qualitative

observations, software used simultaneously with an experiment, computer simulations and projects might all be included within a sequence.
Projects are particularly useful in ensuring that students work under their own direction. If this is to happen a generous time allocation has to be given to project work, possibly several weeks. This supposes to accept to diminish a curriculum crowded by content.

3 - A major outcome of the project is recognising the importance of differentiating between the effectiveness of labwork in terms of promoting learning outcomes, and in terms of the success of labwork at engaging students in particular activities. Both types of effectiveness should be involved in labwork.
It is particularly important for students to be given the opportunity to undertake experimental approaches for themselves, to design experiments, to go through a complete sequence of data processing and to make corresponding decisions about the choice of apparatus, mathematical tools or software. Such activities during labwork cannot be directly linked to specific learning outcomes. However they are crucial for the development of students' scientific understanding in the broader sense.
Linked to effectiveness, specific assessment strategies have to be implemented. Some suggestions about the wording of questions allowing the assessment of specific objectives such as procedures or epistemological meta-knowledge, can be found in case studies from the project.

4 - A condition for improved effectiveness is a different focus for teacher education and a deep change in the focus of resources, labwork sheets and the types of guidance available to students during labwork
The critical role of teachers in ensuring that labwork is effective was emphasised.
For instance, some teachers have a role of labwork developers : they should work in collaboration to identify learning objectives, possibly consulting literature and/or the Internet. They should
also abandon some possible learning objectives to promote others identified as being particularly important. They have to design lectures to be done at a level and with objectives consistent with labwork. In addition, during labwork, teachers have to ask questions to students, and require them to make observations or measurements, calculations of orders of magnitude, mathematical modelling, predictions, etc. as described previously.
The multiple tasks of teachers suggest that it requires specific input during initial and in service training.

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

Autonomy and motivation are expected as consequences of targeted labwork.

ANNEX 2

List of Working Papers of the project 'Labwork in Science Education' 1998

∗ 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 .

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

∗ Working papers 2 and 3 ∗

SCIENCE TEACHING AND LABWORK PRACTICE IN SEVERAL EUROPEAN COUNTRIES

Volume 1 Description of science teaching at secondary level

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

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

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

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

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

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

Language : English

∗ Working paper 4 ∗

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

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

Language : English

∗ Working paper 5 ∗

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

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

Language : English

∗ **Working paper 6** ∗

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

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

Language : English

∗ **Working paper 7** ∗

CASE STUDIES OF LABWORK IN FIVE EUROPEAN COUNTRIES

Editors : Dimitris Psillos and Hans Niedderer

Language : English

*** Working paper 8 ***

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

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

Language : English

∗ **Working paper 9** ∗

CATEGORY BASED ANALYSIS OF VIDEOTAPES FROM LABWORK (CBAV): METHOD AND RESULTS FROM FOUR CASE-STUDIES

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

Language : English

∗ **Working paper 10** ∗

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

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

Language : French.

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

∗ **Working papers in each country**

(France, Denmark, Germany, Great Britain, Greece, Italy)∗

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

Language : the national language in each country .

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Scientific papers, communications, proceedings and theses concerning the project, can be found in the ANNEX 11 to the final report of the project.

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or at the electronic address of one of the authors, to be found via the CORDIS site of the European Commission.