An Analysis of Labwork Tasks Used in Science Teaching at Upper Secondary School and University Levels in Several European Countries

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Received 10 August 1998; revised 14 July 2000; accepted 18 September 2000

ABSTRACT: This article describes the results of a study of the similarities and differences in laboratory tasks used in science education at upper secondary school and university level, in the three main science subjects, in seven European countries. The data source for the study was a collection of 75 laboratory instruction sheets for use at school level in five countries, and 90 for use at university level in six countries, selected as being “typical” of practice in these countries. The tool used for analysis was a “map” (or classification system) for labwork tasks. Whilst some differences are noted between the science subjects and between educational levels, the dominant impression from this analysis is of similarity across educational levels, science subjects and countries. Some coding categories arise only very infrequently, suggesting that some possible designs of labwork task are very seldom used. The findings indicate the potential usefulness of this classificatory “map” as a tool for monitoring practice and for raising questions about the use of labwork in science education.

INTRODUCTION

The question of the design and analysis of laboratory activities has long been of interest to teachers, educational policymakers, and researchers in science education. For example, Lunetta (1998) presents a historical perspective within the Anglo-Saxon tradition on laboratory activities in science education. He states that “laboratory activities long have had a distinctive and central role in the science curriculum, and that science educators have suggested that many benefits accrue from engaging students in science laboratory activities” (p. 249). This statement is also true in the French educational tradition where
laboratory activities were officially introduced early in the twentieth century (1902) at the highest level of secondary school (Bécu-Robinault, 1997; Belhoste, 1995). In the first period, from 1902–1925, the teachers had to carry out experiments at the end of the course. From 1925 on, the discussion of the place of the experiments in the course increased. The underlying role of using experiments to verify what was taught was questioned and experiments began to be used to introduce ideas, adopting an implicitly inductive perspective.

During this century, the teaching time allocated to laboratory activities has steadily and significantly increased from five to six sessions of 2 h over the academic year to 1.5 h per week since 1931. Laboratory activities were also extended to lower secondary school level. Today in France all pupils in the first year of the upper secondary school have laboratory activities in physics and chemistry 1.5 h per week. Despite this extension of laboratory activities, as Lunetta (1998) states, the question of the major mismatches between goals espoused for science teaching and behaviors implicit in science laboratory activities in regular science education is still a relevant one.

In research in science education on laboratory activities, a major orientation deals with improvement of meaningful learning and the specification of relevant goals and activities. The sub-title of the main second section of Lunetta’s chapter (1998), “Towards greater consistency between goals, theories and practices,” highlights an issue that other science educators have also explored and discussed. Many research studies discuss proposals to improve laboratory activities or create new types of laboratory activities rather than analyzing the current practice with regard to laboratory activities. For example, Gil-Perez and Carrascosa-Alis (1994) proposed a problem-solving approach in science teaching (including laboratory work), that teachers should “organize learning as a treatment of problematic situations that pupils can identify as worth thinking about” (p. 307). Others have advocated that laboratory work should include some extended investigative projects (Woolnough, 1994) to give students the experience of being “a problem-solving scientist” (Woolnough & Allsop, 1985, p. 43). Roth (1994) also advocates open-enquiry as a means of making learning tasks more ‘authentic’; that is, making the students better surrogates (in his view) for the activities of research scientists.

Fewer studies have focused on the analysis of practice. Knowledge of typical practice is, however, valuable in itself and particularly for anyone wishing to integrate new and innovative practices into the educational system (Bécu-Robinault & Tiberghien, 1997; Roth et al., 1997). The study presented here deals with the analysis of regular laboratory activities in several European countries at the upper secondary school and beginning of university.

UNDERLYING CHOICES OF LABORATORY ACTIVITIES ANALYSIS

Any analysis of practice raises the question of the choice of categories. Several analysis systems for categorizing laboratory activities have been proposed in the literature. Here our aim is not to present an extensive review of these efforts, but to situate ours in relation to them. We consider three main types of analysis systems from the point of view of the underlying choices. These choices are not necessarily declared by the authors, but are based on our judgment as to the emphasis of their work.

The first type of analysis system takes the planning of the tasks (the planned activities and the planning of effective activities) as its reference, with categories corresponding to different phases in carrying out a laboratory activity. One example is the analysis categories used by Lunetta and Tamir (1981) to compare laboratory tasks in the PSSC Physics Course and the Project Physics Course. Their four categories are (1) planning and design, (2) performance,
(3) analysis and interpretation, and (4) application, corresponding to a priori phases in carrying out laboratory activities. We would place Ganiel and Hofstein (1982) in the same group, even though an additional category is introduced: “ordering and organizing work.” This category is transverse in that it does not represent a phase of the activity but a competence (skill and ability) which is considered a relevant learning objective of such an activity.

This additional category provides a bridge to the second type of analysis system, which is based on “competency.” This word refers to learning objectives which include skills, declarative knowledge, and reasoning processes such as observing, making hypotheses, measuring, and so on. This approach can lead to very different categories, some global (like observing) and others specific (like reading a measuring instrument, such as a thermometer or a digital voltmeter). These categories are very often used for student assessment by the teachers during the session.

The third type of analysis system is based on a theoretical framework concerning students’ activities in relation to the laboratory situation. For example, Roth et al. (1997) in their phenomenological analysis consider that “every interpretation emerges from the interaction of the ‘horizon’ individuals bring to the situation and the ‘horizon’ of the text/thing” (p. 130). In this approach, the interaction between students’ horizon and an element of the practical situation (a “text/thing”) is central. This study does not present a list of categories as such, but outlines a framework for analyzing students’ investigations: (1) goal; (2) outcome related to physical action and phenomena, including apparatus, observation, and objects; (3) possible outcome for which there is no observable evidence; (4) outcome of a mental action such as model, construal, or hypothesis; (5) outcome of interaction of physical and mental activity, but specifically in terms of physical content, such as a mental model of a new item of apparatus; (6) placeholder in diagram so that repeated action can be modeled consistently; and (7) different types of action.

In our analysis system, the theoretical framework is also based on the interaction between students and the practical situation, but we introduce knowledge as a third specific basis. This might be taken to indicate that we consider knowledge a given “thing” outside people. This is not our position. We differentiate the “knowledge to be taught” which, depending on the country in question, may be specified in the official curriculum, in textbooks, and other support materials (CD-ROM, Web site, etc.) and the knowledge which is shared among the class group. This “knowledge to be taught” is to be acquired by the students, and teaching situations are designed to achieve this goal. On the other hand, during the situation, students are supposed to construct an understanding of this knowledge through their interactions with the elements of the situation, such as questions (given by the teacher or a text), the available information (given by the teacher or a text), and the material objects. We consider that knowledge “lives” in these situations; that it is constructed or mobilized by the teacher and the students through the diverse interactions. This perspective leads to the theoretical positions presented in the following paragraphs.

THEORETICAL POSITIONS

To analyze laboratory activities we focus on the possible elements of the situation with which the students interact and which play a role in constructing an understanding of knowledge. So our “map” of laboratory work (or labwork, for short) has three main dimensions, as shown in Table 1). The first dimension, “intended learning outcome,” specifies objectives associated with the “knowledge to be taught,” while the second and third correspond to two aspects of the situation: “design features of the task” and the “context of the task” corresponding to the organizational aspects of the situation (Table 1 and Appendix). We
focus on the task because knowledge takes its meaning in the framework of the task and is contextualized by the task.

**Theoretical Position on Knowledge**

At this point, our theoretical position on knowledge should be made more explicit. As we are using the term “knowledge,” it includes skills. This strong position is based on features of cognitive processes involved in observation and experiment. The features presented by Gooding (1992), who studied the way scientists (in particular, Faraday) construct their productions, are (p. 47): (1) their nonlinearity—reflexiveness, recursiveness, and multiple pathways between goals and solutions; (2) the importance of human agency in the manipulation and transformation of real and imaginary objects; (3) the interaction of concepts, percepts, and objects (“head and hand”); and (4) the creative possibilities opened up by uncertainty.

This interaction of concepts, percepts, and objects (which we understand as perceived events or objects) raises a crucial problem for researchers in science education. It is involved in both scientists’ or students’ cognitive processes in their understanding of new phenomena and/or theories. The problem is that even if the material objects and events are the same, students’ and scientists’ concepts are not the same, nor are their intricate percepts. Many research studies in science education show that it is not sufficient that students see, touch, or hear something that is in disagreement with their prediction to modify their understanding of this perceived event (or set of events) even if, on the spot, they recognize the disagreement (Chinn & Brewer, 1993; Duschl, 2000; Tiberghien, 1998). These intricate percepts and concepts in relation with objects are also involved when the teacher, who knows science, interacts with the experiment. However, the teacher’s set of concepts/percepts is often different from the students’. This difference between students’ and teacher’s intricate percepts and concepts is a major difficulty in teaching/learning science. To overcome this difficulty, the design of relevant teaching situations needs to take account of this difference. In order to do so, the analysis should aim to differentiate concepts and percepts. As a matter of fact, an event (or set of events) is a common reference point for the teacher and the students, so a first aim is that the “class group” (the teacher and students together) shares a common description of this event in terms of material objects and perceived events.
Another teaching step can be to focus on the explicit differences between the students’ and teacher’s interpretations, or to ask students to extend their interpretations to test them via experiments, and so on. Whatever the teaching choice, theoretical and modeling aspects are involved in this step even if students’ theory and models are at odds with the teacher’s theory and models. To dissociate concepts and percepts in relation to objects is necessary to specify the differences between students’ and teacher’s approaches so that they do not remain very global. If they do remain global, the students’ learning path is more difficult. It is then necessary to make it explicit that the descriptions, interpretations, and predictions are either in terms of material objects and events or in terms of theory and models. This is a way to improve understanding between the teacher and the students. It is also a way to avoid the very frequent students’ judgement that science is arbitrary in what it emphasizes and ignores. This is a reason to separate what we call the world of objects and events and the world of theories and models. This separation into two major categories does not deny that concepts and events are integral to cognitive processes, but allows a deeper analysis of the differences between students’ and teacher’s interpretations. Moreover, this separation is also consistent with the idea of experimental validation in science, which, in the written publications, requires a separation of the reports on experimental fact (which belong to the world of objects and events), theoretical aspects (which belong to the world of theory and models), and experimental facts (which belong to the world of objects and events).

This separation leads us to introduce two main categories in our laboratory activities analysis: what the student is expected to do with physical objects and what the student is expected to do with ideas.

Effectiveness

Another orientation of our theoretical framework is the evaluation of the labwork task in terms of its effectiveness. For this, it is useful to consider the process of developing and evaluating a labwork task (Figure 1). The starting point is the teacher’s (or curriculum developer’s) objectives for the task. These objectives specify what the students are intended to learn from the task. Having decided the learning objectives, the teacher then designs the labwork. Both the objectives and the task design are influenced by the teacher’s views of science and learning, and by practical and institutional factors (such as the resources available, the requirements of the curriculum, its mode of assessment, and so on).

When the labwork task is implemented, it is possible to observe what the students actually do on the task and to attempt to assess what they actually learn. Both of these will be influenced by the students’ views of science and learning, and by the practical and institutional setting. Some students, for instance, will concentrate on those aspects of the task that they believe will gain them the most credit in terms of course grades. The teacher’s and students’ views may not coincide: for example, the teacher may consider the process of practical enquiry to be very important, whereas the students are more concerned with being told the “right answer.” As a result, the students’ actions in response to the task may not be what the teacher (or curriculum developer) intended. So one measure of effectiveness (“effectiveness 1”) is the extent to which the students’ activities match those that the teacher intended. A second measure of effectiveness (“effectiveness 2”) is the extent to which the students’ learning matches the learning objectives.

If a labwork task is found to be effective in one or both of these senses, it is then important to ask which aspects of the task design lead to its effectiveness. Conversely, if we find that a task is less effective than we had hoped, a detailed analysis of the task design may help us see how it can be redesigned. In both cases, therefore, it is useful to have a full and systematic description of the main elements of task design.
DESIGN OF THE STUDY

Context of the Study

The work reported in this article took place in the context of a two-year European project focusing on laboratory activities at the upper secondary school and lower university levels. This project, "Improving Labwork in Science Education (LSE)," involved research groups from six European countries. In order to provide a common framework for a series of surveys (of practices across Europe and of teachers’ and students’ views on labwork) and a
set of detailed case studies of both “traditional” and more innovative examples of labwork, a classification system was developed for describing in detail the characteristics of any given labwork task. The outcomes and effectiveness of labwork could then be addressed in a uniform way across this multinational research project (Millar et al., 1998, forthcoming; Psillos et al., 1998).

This two-year work of seven research teams from different European countries offers a rather rare opportunity to collect information on the regular teaching practices in these countries. It is interesting to note that among the group of researchers in this LSE project, there was at the outset little mutual knowledge of the different organizations and practices of the educational systems, even though some of them are deeply different.

**Analysis of Laboratory Instruction Sheets (Labsheets)**

In this article, the “map” designed within the framework of the European project LSE is used as an analysis tool applied to instruction sheets for laboratory work (labsheets) in order to describe the regular practice with regard to laboratory activities in science education in Europe at upper secondary school and lower university levels. The “map” itself is fully described in Millar et al. (1998).

Several reasons justify the decision to use labsheets as the materials for analysis. First, within the European project LSE, it became clear that the labsheet is used in all countries by most teachers. The use of labsheets is not specific to teaching practices in certain countries, but is an international practice wherever labwork activities take place, whatever the organization of the educational system. Therefore, labsheets are very representative of usual practice in science education and play important roles in laboratory activities in science teaching. The labsheet’s importance stems from its ubiquity in practice and its key roles in guiding students’ actions and learning.

Second, the labsheet strongly conditions the students’ activities during labwork. One of the main conclusions of several case studies of labwork activities carried out within the framework of the LSE project (Bécu-Robinault, 1997; Buty, 1998; Leach, 1998; Sander, Niedderer, & Schecker, 1998) is that the type of question asked has a strong influence on the students’ activities and, in particular, on the type of knowledge involved when students carry out the sequence of required tasks.

Third, because the labsheet is a teaching tool that is very typical of practical science education and has a strong influence on students’ activities, it could be said to belong to the core of current science educational practice. This core deals with the fundamental relationships between student, teacher, and knowledge (Brousseau, 1981). Elmore (1996) uses the same idea of a “core of educational practice,” explaining that by this he means “how teachers understand the nature of knowledge and the student’s role in learning, and how these ideas about knowledge and learning are manifested in teaching and classwork. The ‘core’ also includes the structural arrangements of schools, such as the physical layout of classrooms, student grouping practices, teachers’ responsibilities for groups of students, and relations among teachers in their work with students, as well as processes for assessing student learning and communicating it to students, teachers, parents, administrators, and other interested parties” (p. 2). From this perspective, a labsheet belongs to the core as a tool for communication between teacher and students and also with others.

From the students’ point of view, the labsheet is the explicit and formal means used by the teacher to tell them what they have to do during a labwork session, to regulate the time of the class during labwork activities, and thus to keep it under control. From the perspective of external accountability, the labsheet provides a record of the class activity, which can be shown to inspectors, parents, teacher trainers, and others interested in science teaching.
Therefore, analyzing a labsheet can provide information about the main features of labwork activity that the teacher makes explicit. Of course, the role played by the labsheet depends on the teacher’s practice with regard to the level of detail provided and the type of question asked. Clearly, depending on the teacher’s style of teaching, there can be a lot of variation in the way any labsheet is used in the classroom.

For these reasons, we decided to carry out an analysis, using the labwork “map,” of labsheets from different countries. This choice aims to improve our knowledge of the phenomena of regular education, which characterize the educational system. In that case, the effectiveness is not addressed, because a comparison between *a priori* analysis and what actually happens cannot be carried out using labsheets as the data source. In this analysis, our primary aim is to identify the main features of labwork tasks as reflected in the labsheets provided and to see whether similarities and differences emerge between levels of the educational system or between the main science disciplines.

**RESEARCH METHODS**

Due to our theoretical choices regarding the role of labwork sheets in students’ activities, we decided to use, as primary data for a study of the variety of labwork tasks, the written instructions sheets (labsheets) which are given to students to inform them about a labwork task and to guide them through it.

In fact, written instruction materials are the ideal medium for studying the regular practices in different countries, as they embody the decisions and perspectives that shape that practice. The choice of labsheets is implicitly recognized as relevant by Lunetta (1998) when he writes that “in spite of attempts to reform curricula, students worked too often as technicians following ‘cookbook’ recipes. . . .” (p. 251). However, our hypothesis is much less restrictive. We only state that the use of labsheets is a regular science teaching practice in many countries and in several educational system organizations, most of which are very different from those that have evolved from the Anglo-Saxon tradition (Tiberghien et al., 1998).

Six research groups from different European countries involved in the LSE project (Denmark, England, France, Germany, Greece, and Italy), plus a group from Spain indirectly associated with the LSE project, were each asked to identify five labwork tasks representative of current practice in their country at senior secondary school and first-year university level, in each of the three main science subjects (biology, chemistry, and physics). In total, 165 labsheets were collected: 75 labwork instruction sheets used at school level in Denmark, England, France, Germany, and Spain, and 90 instruction sheets used at early university level in Denmark, England, France, Germany, Greece, and Italy. In the last two countries, labwork is only infrequently used at the secondary school level, hence, their omission from the secondary school sample. For each discipline, five labsheets from each country and level were collected, providing a total of 25 labsheets per discipline at secondary school level and 30 at university level.

The tasks presented on these instruction sheets were analyzed by one person from each national group using the categories of the “map” (see acknowledgements) with the statement that within each subdimension, a labwork task is characterized by selecting the most appropriate descriptor (or descriptors) from a given list, or by ticking a number of boxes in a table. As a check on intercoder reliability, a sample of at least one labsheet per group was recoded by one of the authors. In all cases but one, there was a high level (>90%) of agreement between coders. The exception resulted from an issue of interpretation which was easily resolved through discussion.

We acknowledge that the representativeness of the sample of tasks for each country is based upon professional judgment rather than empirical evidence. Consequently, it is
possible that the choice of one or several groups at one or both levels is not representative of the current practice in that country, the criteria for choice at secondary and university level may be different as different types of teachers were involved.

In both cases, we would expect this to result in distinctive characteristics of that national sample for the level in question. These were not observed. We are also aware that, while the whole sample is of reasonable size, each national sample is relatively small. For that reason, we will focus on patterns and trends within the sample as a whole and by disciplines, rather than on differences between countries.

Because of the relatively small numbers in each coding category and the very large number of potential comparisons between categories, we did not feel it appropriate to use statistical tests in analyzing these data. Comments are based on inspection of the patterns and trends observed. As a rule of thumb, we treated a coding category as “frequent” if it occurred in >70% of labsheets, and infrequent if it occurred in <30% of labsheets.

RESULTS: AN ANALYSIS OF LABWORK TASKS USING THE “MAP”

These results are presented following the three dimensions of the “map” (Table 1).

Dimension A: Intended Learning Outcome (Learning Objective)

This dimension of the analysis considers the principal learning objectives of labwork for each of the main science disciplines at each educational level.

Upper Secondary Level. The analysis of the relative frequencies of the different learning objectives for the 25 biology, chemistry, and physics tasks show that the objective “to help students to identify objects and phenomena and become familiar with them” is common in all disciplines (between 18 for chemistry and 20 for biology), whereas the objective “to help students to learn how to plan an investigation to address a specific question or problem” is infrequent in all disciplines, though slightly more common in biology (2 to chemistry, 3 to physics, and 7 to biology).

Several differences between disciplines appear. Almost all the physics labwork tasks included the objective “to help students to learn a relationship” (21 out of 25), but this was relatively uncommon in chemistry and biology (3 and 7, respectively). The objectives “to help students to learn how to process data” and “how to use data to support a conclusion” were more common in physics than in chemistry or biology. Conversely, the objective “to help students to learn how to carry out a standard procedure” was more common in chemistry (22) than in physics (10) or biology (11). These differences between the disciplines are not surprising, but correspond to the characteristics we might expect of labwork in these subjects.

Few differences between countries emerged. The main differences concerned the objectives “to learn how to use data to support a conclusion” and “to learn how to communicate the results of work.” The French examples put more emphasis on using data to support conclusions, whereas those from Denmark and Germany gave more emphasis to the communication of results.

University Level. At university level, the differences between disciplines are smaller than at secondary level. With regard to the content objectives, it appears that for all disciplines labwork tasks more frequently ask students “to identify objects and phenomena” than “to
learn a theory/model” (23, 16, 17, and 2; 8; 3 out of 30 for chemistry, physics, and biology, respectively), and very few physics tasks are about learning “facts” (4). With regard to the process objectives, the pattern is similar to that in the school-level tasks, with objectives related to data processing and use more common in physics, and a greater emphasis on learning how to carry out standard procedures in chemistry.

Comparison of Upper Secondary School and University Levels and of Science Disciplines. If the sets of school and university level tasks, regardless of science discipline, are compared, the similarity in objectives is very striking, even though the type of teacher and teaching involved may be quite different. Moreover, the cumulated results for secondary and university levels (Figure 2) show a strong similarity between disciplines for most of the objectives (in particular 1, 3, 4, and 8), while at the same time highlighting those objectives which we would expect to be more common in chemistry [carrying out a standard procedure (7)] and in physics [learning a relationship (4) and processing data (9)].

Dimension B1: Design Features of Task

The second main dimension of the map aims to characterize the design features of labwork tasks. There are several distinct aspects of the design features of a labwork task. One, relating to the objects and observables with which students are asked to interact, informs us about the
nature of the physical activity, including perception, which is involved in the labwork task (subdimension B1.1). Another very important aspect relates to the ideas that are involved in the tasks (subdimension B1.2). This gives us information about the way in which the phenomena observed or produced in the labwork task are to be taken into account. These categories indicate to what extent concepts and percepts in relation to objects are involved, differentiated, and put in relation. As we discussed in the theoretical part, the underlying model here is of labwork as involving an interplay between the descriptions of the observable things or actions in terms of material objects and perceived events which belong to the world of objects and events on the one hand, and the theoretical interpretations, predictions, or explanations which belong to the world of theories and models on the other.

**Subdimension B1.1: What the Students Are Expected to Do with Objects and Observables.** Subdimension B1.1 relates to what students are expected to do with objects and observable things in carrying out a labwork task. The “map” also allows us to record the source of the information acquired by the students (inside or outside the laboratory, from a computer simulation or CD-ROM, or from text).

**Upper Secondary School and University Levels.** The results of this analysis (Figures 3 and 4) show similarities at upper secondary school and university levels. In almost all labwork activities, students have to use some material objects and observe something, including a measurement apparatus. Only very rarely do the students have to present, display, or make something. Students are most frequently expected to:

- Use a laboratory device in physics or a laboratory procedure in chemistry and (to a lesser extent) in biology;
- Make an event occur, in all three disciplines;
- Observe an event, in all three disciplines, and also, mainly in physics and in chemistry, to observe a quantity (i.e., to read a measurement apparatus).

It is also striking that, particularly in physics, some coding categories apply to the majority of labwork tasks, and some almost never apply. This is less marked in chemistry and much less in biology. For instance, at upper secondary school level, 22 of the 25 physics labwork sheets ask the students to “use a laboratory device or arrangement,” 20 ask them to “observe a quantity,” while none asks them to “present, display, or make an object” or “observe a material.” In chemistry, 21 labwork sheets ask the students to “use a laboratory procedure,” while none asks them to “present or display an object.” In biology, no single coding category arises >20 times, and none has zero frequency. This may be evidence of a tendency for labwork in physics to involve students in carrying out a smaller range of types of action with objects and observables than corresponding labwork in biology, with chemistry coming somewhere in-between.

**Sources of the Information Acquired by the Students.** Another aspect of subdimension B1.1 is the origin (or source) of the information acquired by the students (from the real world, inside or outside the laboratory; from computer simulation or CD-ROM; from video; and from text). At upper secondary school, it emerges very clearly that there is almost exclusively one single source of information for students in all countries and disciplines: material objects inside the laboratory. Only in biology does it appear that, on a few occasions, information is acquired from outside the laboratory. Information is almost never
What students are expected to do with objects and observables in labwork tasks at upper secondary school and university levels.

Obtained from text (different from the labsheet); the emphasis is on obtaining information using real devices. At university level, the origin of the information acquired by students is a little more varied. In biology there are a few tasks in which information is acquired from outside the laboratory and from video. Also, particularly in physics, the role of the text as a source of information becomes more frequent. The most common source of information, by a large margin, remains real objects and devices inside the laboratory.
SubDimension B1.2: What Students Are Intended to Do with Ideas. Subdimension B1.2 relates to the second important aspect of task design, what the students are expected to do in the domain of ideas as they carry out the labwork task.

Upper Secondary School and University Levels. The results of the analysis of labwork sheets on this subdimension are shown in Figures 5 and 6. Two striking features should be noted: the similarity between the secondary school and the university level data for all disciplines, and how narrowly selected the students’ activities are during labwork.

A priori whereas the similarities between secondary and university levels in the previous category: “What students are intended to do with objects and observables” (B1.1) can be interpreted with the commonalities of the experimental environment, the similarities of what they have to do with ideas can be interpreted that an underlying hypothesis is that the level of students’ knowledge on the disciplines does not modify what they have to do with ideas. Actually, this hypothesis is not confirmed by research.

Let us note that this similarity confirms the validity of our results since the collection and coding of laboratory sheets is independent for secondary and university levels.

Two activities, where the disciplines correspond to 60% or more of the 165 laboratory sheets at both levels and for the three disciplines (Figure 3b) are: “direct reporting of observations” (1) and “determine the value of a quantity which is not measured directly” (7). Inversely, some activities are almost never involved: explore relations between objects (3), “invent a new concept (physical quantity or entity)” [which means that the students have to elaborate the model and not construct as such a basic concept] (6), “test a prediction from a guess and from a theory” (8, 10), “account for observation
Figure 5. What students are expected to do with ideas in labwork tasks at upper secondary school and university levels.

by proposing a law, a theory” (12, 14), and “choose between two (or more) explanations” (15). The two common majority items recover different types of implicit learning hypotheses. To do a direct reporting of observations (1) without associating it to testing (8, 10, 12, 14, and 13 in a less extent), strongly suggests the hypothesis that when
students directly report an observation they involve the right interpretation if they carefully observe. This hypothesis, which has been found in regular teaching, is not shared by researchers in science education as we have already mentioned. The high level of the items “determine the value of a quantity which is not measured directly” (7), even if it is higher at university level than at a secondary one, again shows the main typical role given to the laboratory work in regular teaching: making measurements and calculations.

A more detailed analysis (Figures 5 and 7) shows that physics labwork tasks cluster in a relatively small number of coding categories, to a greater extent than those in chemistry and in biology. Only in physics do many labwork sheets ask students to “explore the relationship between physical quantities” (4). Also, in physics, more often than in chemistry or biology, the students are asked to “account for observations in terms of a given law” (13) even if it is rather low. This may reflect the higher prominence of mathematical modeling of relationships between variables in physics than in the other two main sciences. The two most common categories for chemistry are “direct reporting of observation” (1) and “determining the value of a quantity which is not measured directly” (7). In biology, one category which seems more common than in physics or (to a lesser extent) chemistry is “to identify a pattern” (2). Well-known specificities of the disciplines appear.
These results for all disciplines, and particularly in physics, interpreted in terms of relation between the world of objects and events and the world of theories and models, show that regular laboratory sessions involve two distinct types of activities: using objects and observing on the one hand, and exploring relations between physical quantities on the other. Although these two aspects of practice and theory are centrally involved in labwork, their relationship is underdeveloped, as shown by the low levels of most of the items dealing with testing a prediction and accounting for observations.

**Use of a Computer in Relation to What the Students Are Intended to Do with Ideas.** Within subdimension B1.2 of the “map,” a subsidiary feature concerns the equipment available to students for use in handling and processing data. Coding categories allow us to note if the students are expected to use a computer or a pocket calculator or to process data manually. In the sample of labwork tasks analyzed, if we look at those which involve the use of a computer for data analysis, then differences appear between the science disciplines and between levels.

Only in physics at university level was there more than one labwork task that asked students to use a computer. In the tasks involving use of a computer, the computer is mainly used for “exploring the relationship between physical quantities” (4) and for “testing a
prediction” (8, 9, and 10) (10 labsheets out of 30), with the latter category being the more common. Indeed, this was the only category in this subdimension in which the number of labwork tasks involving the use of a computer is similar to or greater than the number of tasks involving calculations made manually or using a pocket calculator.

We can also see a striking difference in the frequency with which computers are used for data analysis as compared to their use as a data source (e.g., through a simulation or data on a CD-ROM). The former use of computers is common in physics at university level, but the latter is not.

Subdimension B1.3: Objects-Driven or Ideas-Driven? This subdimension deals with the question of whether a labwork task starts from operations on objects and leads toward ideas (objects-driven) or vice versa (ideas-driven). The results of analysis of the sample of labwork tasks are shown in Figure 8. There is no clear pattern here, though chemistry labwork tasks at secondary school level seem more ideas-driven than objects-driven, as do physics labwork tasks at both levels, though more noticeably so at university level. The apparently greater tendency of chemistry tasks to be objects-driven at university level than at secondary school level is unexpected and may merit further investigation. At both levels, biology labwork tasks appear to be more objects-driven (and perhaps therefore less “theoretical”) than tasks in the other two science disciplines.

Subdimension B1.4: Degree of Openness/Closure. The fourth subdimension of the design of labwork tasks is about who takes the initiative in labwork activity. Is it the teacher, the student, or the result of a negotiation between them? Five different aspects of the labwork task are considered:

1. The question to be addressed;
2. The equipment to be used;
3. The procedure to be followed;
4. The methods of handling the data collected;
5. The interpretation of results.

Figure 8. Students’ activities: Driven by objects or ideas?
The results of analysis are shown in Figure 9 for secondary school level. At this level, teachers usually make the decisions. At university level, the teacher is still the main initiator. However, particularly in chemistry and biology, the students are increasingly likely to take some decisions as we move from the choice of equipment, to procedures, to data analysis, and to interpretation. In physics, students appear to be given fewer opportunities to make choices about the conduct of labwork tasks.

**Subdimension B1.5: Level of Student Involvement.** This dimension does not give original information since we analyze the labsheet. The students are supposed to work in small groups or individually, but the teacher’s demonstration is excluded.

**Dimension B2: Details of the Context of the Task**

The third main dimension of the “map” describes some important features of the context within which the labwork task is carried out.

**Subdimension B2.1: Duration of Task.** The results show that, at upper secondary school level, the majority of labwork tasks last for one session of about 80 min. In chemistry, it is

![Graph 1: Number of labsheets specified by teacher](image1)

![Graph 2: Number of labsheets decided by discussion](image2)

**Figure 9.** Extent to which students can make decisions in carrying out labwork tasks at upper secondary school level.
almost equally common for a task to cover several lessons of this duration, but this is not the case for physics or biology. At university level, particularly in physics, duration of two or three sessions seems the most common. Although extended projects are, as we might expect, a less common form of labwork, they are used in all three sciences (more commonly in this sample at secondary school level in biology, and at university level in physics and chemistry).

Subdimension B2.2: People with Whom the Student Interacts. Here the pattern at secondary school level seems very clear (and seems to apply in all countries): students are expected to interact during labwork with other students and with the teacher only. At university level, there are clear differences, and other groups, such as more advanced students acting as demonstrators and technicians, are also involved in interactions (Figure 10).

Subdimension B2.3: Information Sources Available to Student. The results show that, at secondary school level, the worksheet (labsheet) is the main source of information and often the only one. At university level, books are a very frequent source of information. Computerized databases are not widely used as data sources at either level. These results confirm those obtained for subdimension B1.1: “What the students are expected to do with objects and observables.”

Subdimension B2.4: Type of Apparatus Involved. For this final subdimension, the results show that standard laboratory equipment is by far the most common type of equipment used. This evidence suggests that computers are seldom used as apparatus (i.e., interfaced to data-logging equipment), although, as we have seen, they are widely used in physics labwork at university level for data analysis purposes. These results confirm those obtained for subdimension B1.3: “What the students are intended to do with ideas.” This shows how restricted the number of activities are that are asked to be done by students.

![Figure 10. People with whom student interacts during labwork.](image-url)
CONCLUSIONS

The method of characterizing a labwork task using the dimensions and subdimensions of the “map” and the coding categories associated with each of these draws attention to several issues concerning the practice of laboratory activities on one hand and the map as an analysis tool on the other.

Concerning the Map as a Tool

As a tool, the “map” appears to be effective for discriminating between laboratory activities. Two principal consequences follow: it allows us to identify some distinctive aspects of disciplines and to show that some types of activity are very frequent and some are infrequent.

The way in which the map highlights both high and low frequency of items leads us to consider it as a very helpful tool for designing a teaching sequence of a series of laboratory activities which takes into account the range of activities that is necessary to promote understanding of the “knowledge to be taught” in relation to the relevant available information. Obviously, this implies making such activities explicit. The map is a guide to that process, where the underlying theoretical hypotheses are shared and the learning hypotheses are made explicit.

This type of tool is all the more relevant because recent studies show that the way questions are formulated deeply influences the students’ activities. For example, Bécu-Robinault (1997) shows that students answer questions using only the “world” that is explicitly involved in the questions. It might be valuable to develop this map further in order to be better able to discriminate types of questions with regard to the information they provide in order to have a finer grained analysis.

Concerning Typical Practice

Several general conclusions can be drawn:

1. In general, there is coherence between the learning outcomes (A) of labwork tasks on one hand, and what the students have to do (B1.1 and B1.2) on the other hand. The main objective for all disciplines, “identify objects and phenomena and become familiar with them” correlates well with “to make direct reports of observations,” particularly at secondary level. Similarly “to learn a relationship” in physics tasks correlates with students’ activities “to observe a quantity” (i.e., read a measurement apparatus) and “to determine the value of a quantity which is not measured directly.” The objective appears, however, to be restricted to a quantitative aspect of relationships.

2. The specificity of the disciplines appears in what the students have to do, particularly in chemistry (how to carry out a standard procedure) and in physics (learn how to process data), then the map is able to discriminate these differences.

3. In all disciplines, there are striking patterns with regard to what the students have to do and what they are not asked to do during labwork. At secondary school, the students often have to make direct reports of observations, but they do not often have to present or display or make an object. They seldom have to explore relationships between objects, test a prediction, choose between two (or more explanations), or invent a new concept (or entity). Even at university level, it is rare for students to have to test a prediction from a guess or from a theory (though in physics they are quite often asked to test a prediction from a law) or to be asked to account for observations in terms of a law or a theory. A conclusion that might be drawn is: in typical labwork,
only actions with objects and observables and a small range of specific theoretical aspects are involved; there is little emphasis on the relationship between the domain of objects and observables, and the domain of ideas related to theoretical aspects. The high frequency of the coding category “direct reporting of observation(s)” shows that regular laboratory activities do not help students to construct new relations between concepts, percepts, and objects. They are supposed to either discover the new relations or the concepts by themselves or to use theory that has already been taught. In this last case, students have by themselves to construct a new set of intricate concepts, percepts, and objects, without being helped to “disentangle” their initial knowledge.

4. The comparison between disciplines shows that physics is perhaps closer to its “caricature” than chemistry and biology. For example, Figure 3a (showing what students are intended do with ideas) indicates the frequency of the two categories dealing with relations between physical quantities, whereas chemistry and biology have fewer categories which arise very frequently. However, major common tendencies appear among the three disciplines.

Our findings corroborate the outcomes of an analysis of the laboratory handbooks of two important projects of the 1960s: Project Physics and the PSSC (Lunetta & Tamir, 1981). One of their conclusions is that “differences in orientation between the PSSC Laboratory Guide and the Project Physics Handbook are not as easy to detect from the results of this analysis as might have been expected” (p. 640). In our case, our results show commonalities on laboratory activities between countries having different educational systems due to their own history and culture. These results show how restricted is the number of activities which are given to students.

Why this similarity? At this point, we can only offer some conjectures. Labwork activity is constrained by the teacher’s view of science and of learning and by the constraints of the practical and institutional context. The level of similarity observed suggests the following hypothesis: to manage a labwork class where several small groups of students are working with objects and apparatus, the teacher wants to have similar activity going on in the different groups so that, at the end of the session, the students are not too far apart. This is a condition for managing the subsequent teaching session, which might be a lecture or another practical task. If the students have not undertaken the same activities, the teacher’s task may become too difficult. Such a consideration might then lead the teacher to give rather strong guidance and to choose activities which are not likely to be too divergent in outcome.

Another interpretation would be that the teacher, by ignoring the necessity of taking explicit responsibility for “disentangling” students’ concepts and percepts in relation to objects, present activities which focus on observing and giving a direct report of observation, or identifying a pattern and then dealing directly with the physical quantities, which allows him or her to sustain a “science discourse” that is acceptable to the students even when they do not effectively understand it.

This similarity leads us to wonder if there is an implicit international paradigm of labwork in science education. If so, the success of any innovation in the use of labwork will depend upon recognizing and addressing this hard core of science teaching practice. Seen from this perspective, our results may provide a useful starting point by highlighting the kinds of activities that appear to be uncommon in current labwork. But, if our longer term goal is the improvement of labwork, we also need to be aware of the tacit institutional “norms” which may be operating across national boundaries.
APPENDIX

The Map: Labwork Task Profile Form

A. Intended Learning Outcome (Learning Objective)
(tick one or more boxes) To help students to . . .

| Content:               | Identify objects and phenomena and become familiar with them |
|                       | Learn a fact (or facts)                                      |
|                       | Learn a concept                                             |
|                       | Learn a relationship                                        |
|                       | Learn a theory model                                        |
| Process:              | Learn how to use a standard laboratory instrument or piece of apparatus |
|                       | Learn how to carry out a standard procedure                  |
|                       | Learn how to plan an investigation to address a specific question or problem |
|                       | Learn how to process data                                   |
|                       | Learn how to use data to support a conclusion                |
|                       | Learn how to communicate the results of labwork              |

B1. Designed Features of the Task

B1.1. What Students are Intended to do with Objects and Observables
(tick one or more boxes)

| Use                  | An observation or measuring instrument                      |
|                      | A laboratory device or arrangement                           |
|                      | A laboratory procedure                                       |
| Present or display   | An object                                                   |
| Make                 | An object                                                   |
|                      | A material                                                   |
|                      | An event occur                                               |
| Observe              | An object                                                   |
|                      | A material                                                   |
|                      | An event                                                     |
|                      | A quantity                                                   |

Source of Data (Transversal Dimension)

| Real world: inside laboratory |
| Real world: outside laboratory |
| Simulation on computer or CD-ROM |
| Video recording               |
| Text                           |
B1.2. What Students are intended to do with Ideas (tick one or more boxes)

<table>
<thead>
<tr>
<th>Report observation(s)</th>
<th>Identify a pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore relation between</td>
<td>Identify a pattern</td>
</tr>
<tr>
<td>Physical quantities (variables)</td>
<td>Objects and physical quantities</td>
</tr>
<tr>
<td>Invent (or “discover”) a new concept (a physical quantity or an entity)</td>
<td></td>
</tr>
<tr>
<td>Determine the value of quantity which is not measured directly</td>
<td></td>
</tr>
<tr>
<td>Test a prediction From a guess</td>
<td>From a law</td>
</tr>
<tr>
<td>From a theory (or model based on a theoretical framework)</td>
<td></td>
</tr>
<tr>
<td>Account for observations In terms of a given law</td>
<td>In terms of a given theory (or model)</td>
</tr>
<tr>
<td>By proposing a law</td>
<td>By proposing a theory (or model)</td>
</tr>
<tr>
<td>Choose between two (or more) given explanations</td>
<td></td>
</tr>
</tbody>
</table>

Tools Available for Processing Data (Transversal Dimension)

| Manual calculation |
| Pocket calculator |
| Computer |

B1.3. Objects-driven or Ideas-driven? (tick one box)

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

B1.4. Degree of Openness or Closure (tick one box in each row)

<table>
<thead>
<tr>
<th>Aspect of Labwork Task</th>
<th>Specified by Teacher</th>
<th>Decided by Discussion</th>
<th>Chosen by Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question to be addressed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment to be used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure to be followed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methods of handling data collected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpretation of results</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B1.5. Nature of Student Involvement (tick one box)

- Demonstrated by teacher; students observe
- Demonstrated by teacher; students observe and assist as directed
- Carried out by students in small groups
- Carried out by individual students

B2. Context of the Task

B2.1. Duration of Task (tick one box)

- Very short (20 minutes)
- Short (one science lesson, say, up to 80 minutes)
- Medium (2–3 science lessons)
- Long (2 weeks or more)

B2.2. People with Whom the Student Interacts (tick one or more boxes)

- Other students carrying out the same labwork task
- Other students who have already completed the task
- Teacher
- More advanced students (demonstrators, etc.)
- Others (technician, glassblower, etc.)

B2.3. Information Sources Available to the Student (tick one or more boxes)

- Guiding worksheet
- Textbook(s)
- Handbook (on apparatus), data book, etc.
- Computerized database
- Other

B2.4. Type of Apparatus Involved (tick one box)

- Standard laboratory equipment
- Standard laboratory equipment + interface to computer
- Everyday equipment (kitchen scales, domestic materials . . .)

The authors would like to thank Dimitris Evangelinos, Dorte Hammelev, John Leach, Naoum Salamé, Florian Sander, and Carlo Tarsitani for their help in carrying out the primary analysis of labsheets.

REFERENCES


