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ABSTRACT

This report is one of a series of reports from a research project that focuses on the evaluation of laboratory work in secondary schools. The study focuses on 12 different laboratory tasks from the biology and chemistry courses of the Finnish comprehensive school. Secondary students (N=212) were observed during laboratory sessions and analysis of the data was aided by a relevant observation scale regarding the aims and goals of teaching. The results of the study indicate that it is important to augment the role of practical work in the evaluation of student performance. Problems related to laboratory safety are also discussed. Contains 83 references. (DDR)

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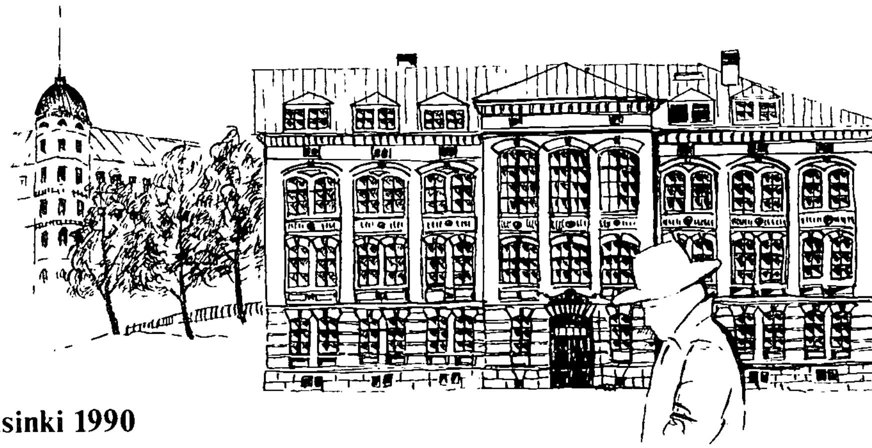
Veijo Meisalo – Matti Erätuuli – Enrico Capaccio

EVALUATION OF LABORATORY WORK IN SECONDARY SCHOOL SCIENCE TEACHING

Development of evaluation methods for the Finnish comprehensive school with emphasis on the biological sciences and chemistry



Helsinki 1990

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DEPARTMENT OF TEACHER EDUCATION

Research report 84, 1990

Veijo Meisalo - Matti Erätuuli - Enrico Capaccio

Evaluation of laboratory work in secondary school science teaching. Development of evaluation methods for the Finnish comprehensive school with emphasis on the biological sciences and chemistry

55 pages

Abstract

This paper is one of a series of reports from a research project, "Evaluation of laboratory work of secondary school pupils", at the Department of Teacher Education of the University of Helsinki. In the present study the project was expanded from physics and chemistry to include laboratory work in the biological sciences. Twelve different laboratory tasks were selected from biology and chemistry courses of the Finnish comprehensive school. The tasks were analyzed and a relevant observation scale was developed regarding the aims and goals of teaching. 212 secondary school students from five different schools were observed during laboratory sessions and their performance as well as the results of the work were analyzed. It was found that our approach provides direct guidelines for the development of the evaluation procedures as well as suggestions for new types of laboratory tasks for the comprehensive school. Even problems of laboratory safety are emphasized in the report.

Key words: Evaluation of laboratory work, Laboratory tasks in school science, Laboratory safety in schools

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HELSINGIN YLIOPISTO

OPETTAJANKOULUTUSLAITOS

Tutkimuksia 84, 1990

Veijo Meisalo - Matti Erätuuli - Enrico Capaccio

Laboratoriotyöskentelyn arviointi peruskoulun luonnontieteiden opetuksessa. Arviointimenetelmien kehittäminen erityisesti biologian ja kemian oppilastöissä

55 sivua

Tiivistelmä

Tämä työ liittyy laajempaan Helsingin yliopiston opettajankoulutuslaitoksella toteutettuun projektiin, jossa on tutkittu aikaisemmin fysiikan ja kemian oppilastöiden evaluaatiota. Tässä työssä tutkimusaluetta on laajennettu biologian oppilastöihin. Tätä tutkimusta varten valittiin kaksitoista erilaista biologian ja kemian oppilastyötä peruskoulun yläasteelta. Valitut oppilastyöt analysoitiin opetussuunnitelmassa esitettyjen tavoitteiden valossa ja tältä pohjalta kehitettiin observointilomake. Koehenkilöinä oli 212 peruskoulun yläasteen oppilasta viidestä eri peruskoulusta ja heitä observoitiin laboratoriotöiden aikana ja myös kyseisten töiden tulokset rekisteröitiin tutkimuslomakkeelle. Tutkimuksessa havaittiin suuria eroja eri oppilastöissä korostuvien tavoitealueitten välillä. Tässä kehitetyt menetelmät tarjoavat viitteitä sekä arviointimenetelmien kehittämiseen että uuden tyyppisten oppilastöitten tuomiseen peruskoulun luonnontieteiden opetukseen. Työssä kiinnitetään myös erityistä huomiota oppilasturvallisuuteen liittyviin kysymyksiin.

Hakusanat: Evaluaatio, oppilastyöt, luonnontieteiden opetus

Preface

The research reported in this paper is part of a larger project on the evaluation of laboratory work on the school level. The project has been made possible through the support of the Department of Teacher Education of the University of Helsinki, and by grants from the National Board of General Education, Finland. The Finnish Ministry of Education provided a fellowship for Dr. Capaccio, who worked at the Department during the spring term, 1987. We would also like to thank our colleagues and the teachers as well as pupils who collaborated with us.

All three authors share the responsibility for this report, with Enrico Capaccio and Matti Erätuuli concentrating on the empirical part and Veijo Meisalo on the theoretical analysis. The use of English was corrected by Pearl Lönnfors, University of Helsinki Language Centre.

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Contents

1 Introduction

History of the project

The Finnish comprehensive school was created in the early seventies, but since then it has been under continuous rapid development, for instance abolishing the possibility of streaming in the mid eighties. The curriculum, as well as the teaching practice of sciences on the lower secondary level in the comprehensive school, has emphasized laboratory work. For instance during 1981-82 it was reported that 95 % of the schools had practical work at least every second lesson (90 min. session). However, the feedback from the school practice implies that students and teachers do not see the real value of the work in the science laboratory. One of the possible ways to improve the situation, that has been suggested on different occasions, is to augment the role of practical work in the evaluation of student performance.

From the beginning of our project we have been cooperating closely with the national school authorities in Finland. The need to emphasize practical work, demonstrated by the first stage of our project, effected in part that teachers were advised to place greater stress on the informal evaluation in the final grade of students in physics and chemistry, where laboratory work was important. Since the problems of subjectivity are obvious in informal evaluation, the new teachers' guidelines for evaluation procedures in physics and chemistry, given by the National Board of General Education, included several principles pointed out in our preliminary reports (cf. Erätuuli & Meisalo 1982). The aims and goals of science teaching were already formulated to more early include individual observations and practical work performed by the student. It was stated unequivocally that the student's performance in practical work has to be an essential part in the evaluation of his ability in science. Suggested methods of evaluation were structured observation and the use of practical test items, paralleled with standard pencil-and-paper tests.

Our first studies concentrated directly on the evaluation of laboratory work of lower secondary school pupils to develop especially methods of evaluation in physics and chemistry (cf. Erätuuli & Meisalo 1982, 1985). As stated above, our project was in close cooperation with the development task of the national curriculum, particularly in the area of physics and chemistry in the comprehensive school (grades 7 to 9). In 1986 we became more interested to widen the area to include the biological sector of the curriculum. It can be noted that in the biological sciences the above problems have aroused little interest in Finland. For instance, a recent book used in teacher education (Virtanen & Kankaanrinta 1989) does not at all discuss the evaluation of practical work.

1.2 Survey of the literature

The tradition from the nineteenth century in science teaching has emphasized demonstrations as an essential feature of science teaching. A later trend was to emphasize the role of laboratory work from the viewpoint of acquisition of skills as well as for reasoning (cf. Kerr 1964, Lock, 1988). For instance Head (1985) analyses the value of practical work on psychological grounds. Morris (1983, p. 57) claims, that "it is an established fact that science teaching is inefficient without well-organized laboratory work". However, it is not

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obvious what "efficient" or "inefficient" means in this connection. For instance, the review by Shulman and Tamir (1973) presented the clear-cut conclusion that, when measured by standard achievement tests, the benefit from laboratory work is dubious.

Bleichroth (1988) and Blosser (1988), among others, have lately revived the question of the good and not so good aspects of laboratory work. Different research groups and experts have developed methods to evaluate laboratory work starting from the processes and outcomes of practical work in the laboratory (see e.g. Thomas 1971; Mackay, 1975; Lunetta & al. 1981; Kohlstrung 1988). We understand that the correct measure of efficiency should be in achieving the aims and goals of science education. The standard achievement tests often measure skills and knowledge emphasizing essentially different matters than those put forward by experts of laboratory work. The aims and goals of the curriculum of the Finnish Comprehensive School will be analyzed in more detail below.

1.3 Analysis of the aims and goals of science in the curriculum

The curriculum of the Finnish Comprehensive School is based principally on a committee report published in 1970 (anon. 1970). While the general goal of the Comprehensive School is the development of the personality of each pupil, the subject-oriented goals of biology teaching stress the following aims:

acquaint pupils with living nature, also especially with human body, its structure and vital functions, as well as those phenomena which are important for a human being as a member of a society,

- to make clear the dependence of all living creatures on each other and on all nature, and also the responsibility of human beings as agents of change in nature, as well as users of natural resources,
- to guide pupils to make observations in nature and to make conclusions based on them, as well as help them to use inductive reasoning,
- to train pupils in independent acquisition of information, even from printed sources,
- to guide pupils to understand the beauty of nature, and to spend their leisure time in nature,
- to arouse in the pupils an interest in the studies of living nature and in an active pursuit to protect the environment and the possibilities of living. The aims of physics and chemistry, which are presented together in the curriculum, are:

- to enable the pupils to acquaint themselves with the most important natural phenomena and with the natural laws conceivable through these phenomena, as well as to present the most important applications

- to let the pupils learn the working methods of physics and chemistry so that they also comprehend how they are applied in different fields of practical life

- to arouse interest in scientific studies, and to offer materials for the construction of the scientific view of the ld

- to develop skills of observation and evaluation, autonomous behavior, dexterity, and comprehension of causal relations.

The subject oriented aims have been slightly modified in the mid eighties, and the detailed curricula are now formulated on the municipal level. The main trend in the changes has been to observe more closely the general aim of the curriculum in the subject oriented goals. However, the schools in our study still followed the earlier curriculum.

The methodical recommendations as well as the Teachers' Guides, published by the National School Board, advise that all chemistry and the major part of biology lessons should be held in a school laboratory or conducted by making observations and doing experiments in nature. They also state, that the aims of the curriculum should be interpreted in order to emphasize both openness and the practical aspects of school work.

1.4 Relevance of the present school practice to the aims and goals

In grade seven there is one 45 minute teaching period in chemistry and another in biology per week. In grade eight there is a double teaching period in chemistry and two single ones in biology. In grade nine there are only two periods in biology. The National Board of General Education recommends that all chemistry and the major part of biology lessons should be held in a school laboratory or conducted by making observations and doing experiments in nature. The pupils [illegible]ly work in groups of two in the school laboratory, but occasionally there is a need for larger groups or a possibil-

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ity for individual work.

It is interesting to note, that in the Finnish school practice it is not usual that biology and chemistry are taught by the same teacher. The most common combinations of subjects for one teacher are, on one hand, mathematics, physics and chemistry and, on the other, biology and geography. Only rather recently, with the introduction of information technology as a new elective subject, have the above traditional combinations been partly broken.

2 Theoretical outline

2.1 Essential dimensions of teaching/learning situations

The teaching and learning situation in a school classroom or laboratory is very complex. It is important, that the teacher is able to analyze her or his work as to the most essential aspects of the situation. At our Department we have developed a method of analysis (cf. e.g. Meisalo 1985, Meisalo & Erätuuli, 1985) where the essential dimensions in the teaching of science are 1) Human exchange vs. independence, 2) Connection to the real world (direct vs. through concrete or abstract mathematical models), 3) Level of logical thinking. This model of analysis is presented in Fig. 1.

In Fig. 1 the first dimension has three categories: Teacher dominated, dominated by social interaction, and independent work by pupils. These categories serve as examples to clarify the nature of this dimension. Human interaction has been considered as the most essential pedagogical dimension in the Finnish research tradition. It is possible to differentiate further the above categories to include, for instance, several different types of group work. As an example we may mention that it is common in the Finnish science classroom for pupils to work in pairs. Here the group dynamics is essentially different from when the number of pupils in the group is larger.

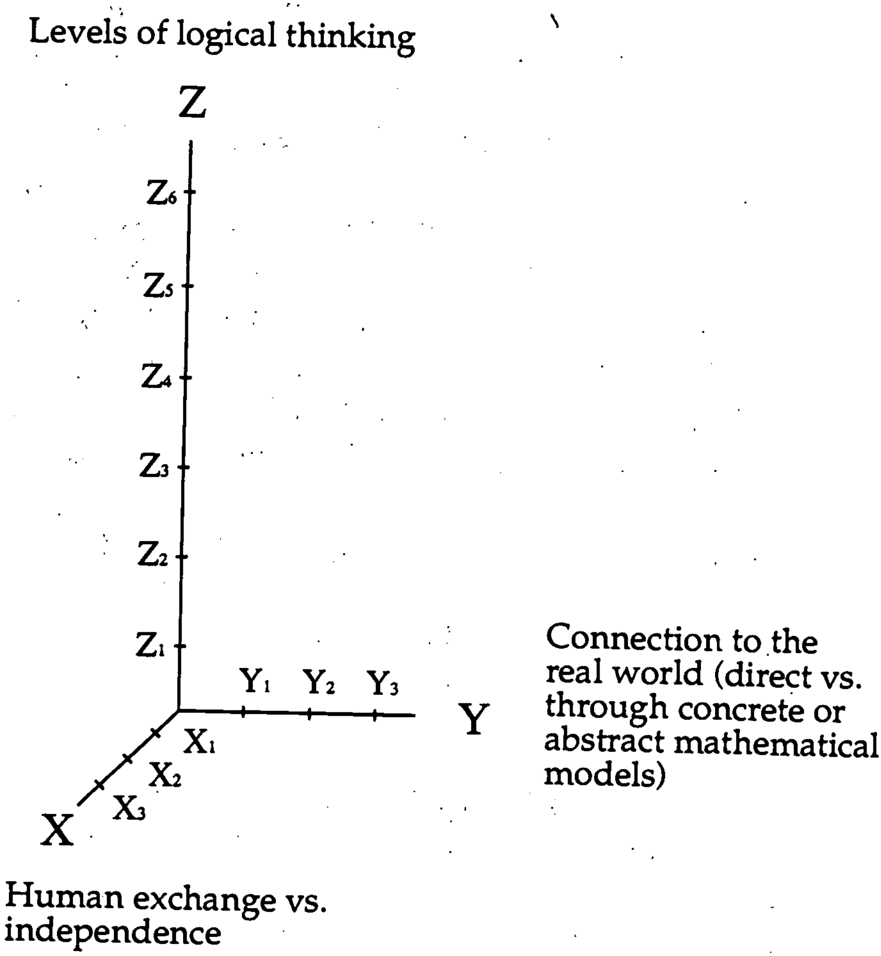

Figure 1. The threedimensional model of analysis of teaching/learning situations

The second dimension is the connection to the real world. This aspect of teaching is most essential to all science subjects, and it should affect both planning and the actual school work on all school levels. Studies directly in nature, observations and experiments, even in laboratory conditions, are essential for the understanding of natural phenomena as well as for creating the emotional atmosphere so important for the urbanizing man. As the second category in this dimension, we may consider the use of concrete models, pictures etc. so actively in use in many schools. And for the epistemologically highly-developed sciences, the use of mathematical models is the most abstract level, presented as the third category. Again here we can see the possibility of creating new categories, e.g. differentiating concrete models and pictures into different categories, and observing that dynamic simulations are often essentially different from static pictures, providing the basis for another category of this dimension.

The third dimension considers the level of logical operations involved in the teaching - learning situation. The first, and not unnecessary category, involves the processes of memorization and recollection. The second category is related categorization to concept formation on the basis of the available information. Other logical processes are inductive and deductive as well as analogue reasoning. These categories are related to the hierarchical levels of aims and goals as presented e.g. by Gagne.

2.2 Openness of tasks - freedom to do independent work

One of the main goals of education is to prepare the student for life as an adult, where there are no parents or teachers guiding and helping when confronting different problems. This means that the adults have to be mature enough for independent action, and pupils have to be given the opportunity of experiencing independent decision-making during their school years. Maturation is a slow process, and these opportunities have to be opened gradually starting already on the lower grades. This is related to the first dimension of the above analysis.

We have been interested in these problems for a longer time now (e.g. Meisalo 1980, 1982; Erätuuli & al., 1981). There is obviously a continuing need to find effective methods for advancing and evaluating independent work in the school (Schaffeld 1988).

We may here analyze further the sources of limitations to the autonomy of pupils in three categories (see Fig. 2):

a) Limitations due to the teacher and other pupils

The teacher may be dominating and authoritative giving strict, detailed orders and directives to the pupils. Some pupils may feel safe in this kind of atmosphere, but it prevents the maturation process of the pupils. Also, some pupils may be dominant allowing little individuality in group work etc.

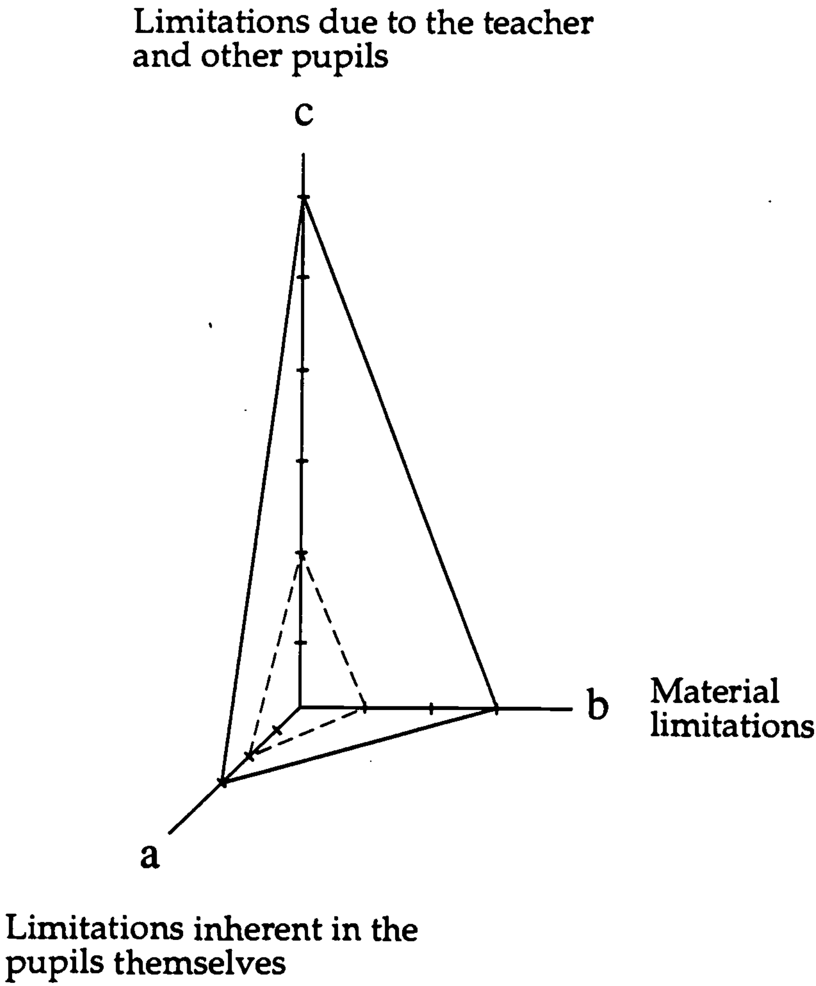

Figure 2. The sources of limitations to the autonomy of pupils as analyzed in three dimensions

b) Material limitations

The role of material limitations is one of the key questions in the present study. The problems presented in the workbook for students may be pure recipes giving no intellectual freedom to pupils. This problem has been analyzed widely in studies of openness of tasks (cf. Erätuuli & al. 1981).

c) Limitations inherent in the pupils themselves

One can not be autonomous without having necessary knowledge and skills, as well as a general maturity for the tasks concerned. The final test of the necessary maturity seems to be the ability of self-evaluation of the outcomes of the work. This idea has been developed to include ready-made forms for practical work Pierow 1988), but it may also be seen more widely.

2.3 Theoretical analysis of the aims and goals of science education

The aims and goals of science education in the Finnish school system has already been briefly analyzed before. Now it is necessary to connect the above theoretical considerations to the goals presented in the curriculum, and to provide the theoretical basis for our empirical approach.

The established goals offer the basis for the evaluation, also in connection with experimental work. We further developed our analysis of the categories of aims and goals to be observed in the laboratory work, as presented in our previous studies on physics and chemistry. The categories are

A. Practical skills

General work habits

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C. Observation of laboratory safety

D. Quality of experimental results

In a further analysis these four categories include the following objectives:

A. Practical skills:

1. To show clearly the full range of relevant manipulative skills
2. To appreciate the precision of the apparatus
3. To be able to obtain quantitative results within an expected range
4. To be able to perform the experiment within a reasonable time
5. To be able to modify the experimental plan creatively
6. To be able to carry out pilot experiments
7. To be able to carry out control experiments

B. General work habits

8. To be willing to work as a member of a team
9. To be able to work independently
10. To be willing to help in running the laboratory
11. To maintain constant attention and to work effectively
12. To be able to make suggestions for further research

C. Observation of laboratory safety

13. To follow safety instructions
14. To perform the experiments neatly and properly
15. To observe the safety of other pupils

D. Quality of experimental results

16. To interpret the data in the light of theory
17. To understand the accuracy and reliability of the data

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18. To understand the meaning of the results
19. To be able to interpret properly the results of control experiments
20. To compare results with data from literature
21. To search for additional information

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3 Empirical approach

3.1 The experimental group

The experimental group in this study consisted of 212 pupils from five different Finnish comprehensive schools. They were on grades seven to nine corresponding to the lower secondary school level and between the ages of 14 and 16 years. For practical reasons all schools in our study were in the vicinity of Helsinki. The teachers volunteered to participate in our study, but the schools had no special characteristics. Teachers evaluated each working group as presented in Appendix 1 below. The groups differed substantially according to these subjective evaluations. It is to be noted that the emphasis in our work is not on the qualities of pupils but on the learning tasks.

3.2 Selection of the laboratory experiments

All twelve experiments which were chosen for this study were usual laboratory tasks presented in the pupils' laboratory manuals used in Finnish comprehensive schools. Most schools use science studies textbooks which include laboratory manuals. The limited time available for the collection of our data to some extent prevented a wider selection of the tasks. However, it was not considered as an essential limitation in our work. The first criterion for choosing an experiment was the amount of planning needed for different experiments. The second criterion emphasized the possibility of achieving the objectives of biology, chemistry and physics teaching. Because it was possible to observe the pupils during only one th, the researchers were not able to analyze the experi-

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ments from this viewpoint. The third criterion was the openness of the experiments. However, here it was only possible to analyze in advance the limitations due to written instructions or the experimental setup. The authors as observers did not want to influence the behavior of the teachers, and thus the role of teachers in the activated openness during a laboratory session could not be estimated in advance.

We had special difficulties in choosing experiments within biology. Our # 4, Model of genetic code, which is actually quasi-experimental, was rather strange to the teachers. Thus the probability model of this task was introduced by the research team in the schools. Experiment # 7, Difference between concrete and Portland cement, was very close to practical life, but the pupils were not able to draw conclusions during the laboratory sessions.

In summary we may state that we selected a small number of experiments and wanted to study them somewhat deeper, setting the ground work for a more extensive empirical approach.

3.3 The observation form

The observation form was formulated by the authors on the basis of our earlier research work, including the theoretical analysis of the dimensions of the laboratory work. The basis for this development work was the epistemological nature of biology, chemistry and physics as sciences, as well as the structure of the goals of these school subjects. It was considered important to include safety aspects in the observation form for all sciences, although these are emphasized to a lesser extent in biology in the Finnish school practice.

In the earlier investigations of this project teachers rated the dimensions of laboratory work on a five step

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scale. The use of such a fine scale proved to be problematic for teachers who were not specially trained for observations. Although it would certainly be possible to get better results with proper training, it was decided to try a three step scale in this investigation to make the observation easier. The observers wrote down 0, if they could not identify any work towards the objective during the session. Similarly, the observers wrote -1, if they concluded that the behavior of the pupil did not lead towards achieving the objective. If they observed behavior which was partly good, partly bad in regard to leading towards the objective, they wrote +1; this kind of behavior was observed only in very few cases, primarily in connection with safety measures. If the objectives of the task were achieved, the observer indicated this by number 2.

The observation form (Appendix 5) also included notes on the openness of the experiment. The observer recorded by whom or by what means the instructions were given to pupils. It was sometimes possible for pupils to work without any instructions, but more often these were given in the laboratory manual or by the teacher. Relevant safety measures were also recorded, especially if there were some special regulations as to use of chemicals, special apparatus or in field work.

The teacher also estimated the general ability of each group on the basis of his or her experience. This is to be compared with the procedure which we followed in our earlier investigations, where individual ability was recorded as the last examination marks in physics and chemistry.

3.4 Collection of the data

The work of (pairs of) pupils in a school laboratory was observed by two observers, using structured observation methods, either in real time in the laboratory or by the session being recorded on videotape, and analyzed later with similar methods. The reliability of the observation method was estimated as rather good, which was demonstrated by the calculated correlation coefficient between the data, by different observers, which was 0.80.

Observations on videorecorded sessions were analyzed in reference with introductory and advanced achievements in science laboratories via SLIC (Science Laboratory Interaction Categories) analysis. The time devoted to experimenting was 22 % - 43 %, listening to instructor's indications 20 % - 30 %, questioning and further investigation 2 %, and writing laboratory reports 20 %. It was concluded that pupils were more interested in confirming facts and collecting data than in broader investigations of nature through exploring, inquiry, and explanation.

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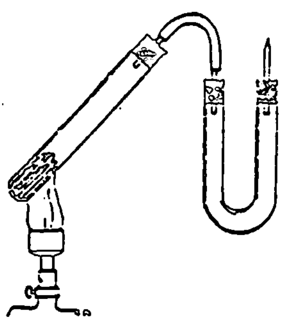
4 Results and analysis of the data

4.1 Analysis of different laboratory tasks

The experiments utilized in this work were selected from those included in the ordinary students' laboratory workbooks used in Finnish comprehensive schools. Twelve different experiments were selected for this study and they are described shortly in Appendix 1. Two examples are also presented below:

The laboratory task # 6 was the study of bacterial growth. Students had to heat a nutrient substratum and to prepare a culture for bacterial growth under sterile conditions. Different specimens with bacterial contamination were put on the Petri dish, and growth rates were recorded during one week working at home. Pupils had detailed instructions for this study in their textbook.

The laboratory task # 9 was the study of the chemistry of carbon. The purpose of the experiment was to identify carbon in organic substances. Pupils were instructed to build, for this purpose, a test apparatus which can be seen in Figure 3 below. Pupils heated organic material, usually a piece of



ure 3. The test apparatus for laboratory task # 9

wood, in the test tube. Pupils verified carbon from the distilled gases by different indicative reactions. Instructions for this laboratory task, as well as a diagram of the apparatus, was in their laboratory manual. They were also supposed to answer eight questions related to the experiment during or after the session.

4.2 Results of structured observation of laboratory tasks

A graphic summary of our results of observations is presented in Figure 4, where data from all laboratory tasks are treated together. It can be seen that the first observed skill, "To show clearly a full range of relevant manipulative skills", was achieved by about 80 % of the pupils. There is a very small percentage of negative cases (dotted area) in the observer markings. The teachers have obviously emphasized manipulative skills earlier.

The second observed skill, "To appreciate the precision of the apparatus", is shown by about two thirds of the pupils. Observers recorded difficulties in the work of about one tenth of the pupils. In about one fifth of the cases this kind of skill was not requested or it was not possible for the observers to record relevant skills. However, it may be stated that this skill is reasonably well developed in the pupils.

The third observed skill, "To be able to obtain quantitative results within expected range", was not relevant to most of the practical work, since the tasks were of a qualitative nature. Thus little can be said with certainty about the skill of pupils, but it seems that when needed, a good major- of them were also able to work quantitatively.

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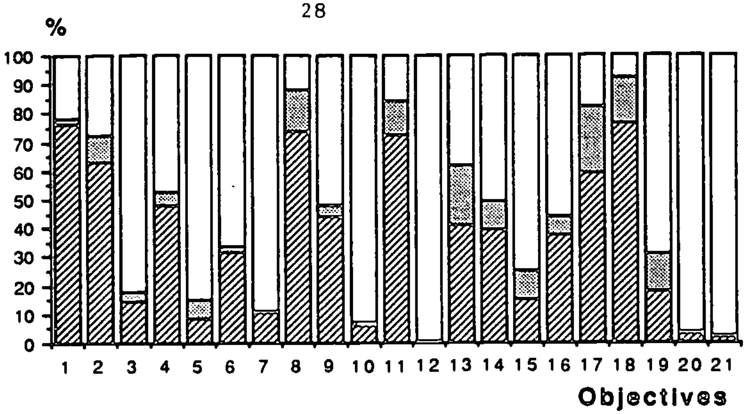

Objectives

A.

1. To show clearly full range of relevant manipulative skills
2. To appreciate the precession of the apparatus
3. To be able to obtain quantitative results within expected range
4. To be able to perform the experiment in a reasonable time
5. To able to modify the experimental plan creatively
6. To be able to carry out pilot experiments
7. To be able to carry out control experiments

B. General work habits

8. To be willing to work as a member of a team
9. To be able to work independently
10. To be willing to help in running of the laboratory
11. To maintain constant attention and to work effectively
12. To be able to make suggestion for further research

C. Observation of laboratory safety

13. To follow safety instructions
14. To perform the experiments neatly and properly
15. To observe the safety of other pupils

D. Quality of experimental results

16. To interpret the data in the light of theory
17. To understand the accuracy and reliability of the data
18. To understand the meaning of the results
19. To be able to interpret properly the results of control experiments
20. To compare results with data from literature
21. To search for additional information

Figure 4. The results of observations of all laboratory tasks. Positive cases marked with diagonal lines, negative cases marked with dotted areas and white areas mean no observations.

The "effectiveness" variable, "To be able to perform the experiment within a reasonable time", demonstrated that one of the problems of the Finnish comprehensive school, lack of time, is not really relevant here! On the other hand, the selection of the experimental tasks in the teaching material was certainly limited through knowledge of the available time.

The following observation categories were: # 5. "To be able to modify the experimental plan creatively", # 6, "To be able to carry out pilot experiments", # 7. "To be able to carry out control experiments". The laboratory tasks in our study hardly offer any possibilities to these more sophisticated aspects of experimental studies.

The following observational items considered general work habits. It can be seen that the school emphasizes more group work than individual work. Item # 8, "To be willing to work as a member of a team", was observed regularly. There were also some difficulties in cooperation with more than 10 % of the pupils. This may reflect the fact that pupils had very few other possibilities for positive cooperation in these grades. On the other hand, many laboratory tasks do not require individual action. Item # 9, "To be able to work independently", was not observed at all in more than one half of the cases. However, there were no major problems in individual work in observed situations.

It is obvious that teachers do not ask pupils to share the responsibility for running the laboratory. Item # 10, "To be willing to help in running the laboratory", was seldom observed. Here we may have a major task for teacher education.

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On the other hand, we may speculate that some safety instructions may inhibit free movement of pupils and thus also prevent the offering of help to the teacher in running the laboratory. On the contrary to the previous item, pupils were rather well prepared "to maintain constant attention and to work effectively" (item # 11). Then, the absence of item # 12, "To be able to make suggestions for further research", shows that teachers do not ask for this kind of behavior. This indicates that teachers should activate open suggestions far more than has been done so far.

The following observational items are related to laboratory safety. These aspects are not emphasized in the aims and goals, but in the practical instructions of running the laboratory. It may be seen that often safety problems are not relevant to the laboratory tasks. However, there were problems in astonishingly many cases. Item # 13, "To follow safety instructions", shows some kind of violation of safety instructions in one third of the relevant cases! Item # 14, "To perform the experiments neatly and properly", shows better results, but again, item # 15, "To observe the safety of other pupils", shows that there has not been enough emphasis in the instructions to follow the safe procedures in the school laboratory. An overall statement of the observers was that the violation of safety instructions was obviously connected to minor general disturbances in the classroom.

Quality of experimental results, including the relation of data to theoretical models, is the last of our main areas of aims and goals. The next observational item, # 16, "To interpret the data in the light of theory", was not relevant in more than one half of the cases. On the other hand, when

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needed the pupils performed rather well in this respect. Here we have registered positive development in recent Finnish laboratory manuals, which even emphasize the need for interpretation of results. In most cases it was also necessary "To understand the accuracy and reliability of the data" (item # 17) and "To understand the meaning of the results" (item # 18). It seems that the teachers fairly emphasize these aspects of experimental work, but that there are also some difficulties. The rather large percentage of failures may be due to the rather high difficulty level of the theory related to some of the tasks.

The last items, # 19, "To be able to interpret properly the results of control experiments", # 20, "To compare results with data from literature", and # 21, "To search for additional information", are seemingly of little importance in the Finnish school laboratories. One may observe essential difficulties in the proper interpretation of data, but the most important result of our observations is that these three observational aspects reflect a demand for higher individual responsibility for the pupils, which is not required in Finnish schools to any great extent.

4.3 Comparison of overall results with data from laboratory tasks # 6 and # 9

It may be of interest to compare the above general results with observational data from laboratory tasks # 6 and # 9, which were described earlier. Figure 4 clearly shows that there are major differences between pupil behavior in these two tasks. In both tasks it appears that items # 10, # 12, and # 20 have not been observed. It may be interpreted that it is rather demanding on these grade levels to ask for sug-

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gestions for further research or to make comparisons with data in the literature. It is a general educational aspect that teachers should more frequently expect help in running the laboratory! In task # 6 it is not at all relevant to obtain quantitative results, or to perform the experiment within a reasonable time, or to perform control experiments, or to observe the safety of other pupils, or to search for additional information. Laboratory task # 9 was obviously rather difficult. A rather large percentage of pupils had difficulties in showing the expected behavior during this session. There was, for example, an alarming number of pupils who did not follow safety instructions. This all may suggest that there is a need for a new emphasis in the practical education of teachers, as well as further development of laboratory tasks.

4.4 Correlation of different items

The correlation matrix of different observations is presented in Appendix 3. There are several significant correlations, but we do not think that the nature of the data would allow a very detailed analysis. However, highest significant correlations (the limit of significance is .181) will be discussed below:

There is a very high negative correlation between manipulative skills and carrying out pilot experiments ($r_{1,6}$ = -0.6). Similarly, there is a high negative correlation between manipulative skills and independent work ($r_{1,9}$= -0.4). It is obvious that many pupils are fond of practical work, show good skills, but will not stop to plan and perform pilot experiments or otherwise show a proneness to independent behavior. The fact that items # 1 and # 11 have a very high, positive correlation speaks favorably for the practically oriented pupils. These pupils also work effectively and maintain constant attention!

The high correlation between items # 6 and # 9 means that the ability to perform pilot experiments and to work independently are related to each other. There is also a high correlation between items # 16 and # 19, as well as between items # 17 and # 18. So there are correlations between using theory and interpreting results of control experiments, and between understanding the accuracy and reliability of the data and understanding the meaning of the results. We may consider that all these items are related to a rather mature understanding of the nature of laboratory work in science.

The high correlation of items # 12 and # 20 shows that the ability to make suggestions for further research, and comparing results with data from literature, are related. It is obvious that both abilities indicate good intellectual maturity. It is also only natural that the difficulty of interpreting the results is dependent on the nature of the practical task.

Items # 13 and # 14 have a high correlation. It has also been observed in the previous studies of our project (Erätuuli & Meisalo 1982, 1985) that to follow safety instructions goes together with performing the experiments neatly and properly. It is interesting to note, that the observation of the safety of other pupils seems to depend more on the nature of the task than on other safety aspects.

Items # 6 and # 11 also have a significant negative cor-

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ation. The observers have possibly interpreted that pupils who are considerate, plan in advance, and may even perform control experiments, work less effectively than those who only concentrate on practical matters. This possibility should be brought to the attention of teachers.

One may draw some conclusions on the difference of pupils' behavior during biology and chemistry sessions. We can see in the correlation table that there are significantly better possibilities to show one's manipulative skills in chemistry than in biology. It may also be easier to perform pilot experiments within biology than in chemistry. It appears that independent work may be more frequent in biology than in chemistry. Pupils also pay more constant attention and work effectively in chemistry than in biology. On the other hand, biology teachers may offer more possibilities for creativity.

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5 Summary and conclusions

5.1 Comparison with previous work in physics and chemistry

This report is a straightforward continuation of our previous work in physics and chemistry. We have presented here some new developments in the general theoretical part, but the emphasis has been on the inclusion of the biological sciences in this project. The empirical part of this study is rather modest. However, it shows that, in the biological sciences, we can use an approach in studying the problems of the evaluation of practical work similar to what we have used in physics and chemistry. On the other hand, it is also obvious that there are many possibilities to further develop this type of work so that it is more fruitful in reference to the most important aims and goals of the curriculum.

5.2 Implications for the science of science teaching

This study reflects the need to bring together new ideas from different disciplines and the value of different types of expertise. This provides an example of possibilities of application of our model of analysis of different pedagogical approaches in science teaching. It is hoped that especially the method of analyzing the autonomy of students in practical work will be of value both in further theoretical analysis and in the development of practical work habits in the school laboratory.

There has not been any cooperation between thr development of curricula and methodical instructions for biology and chemistry teaching in the Finnish comprehensive school. Our data reveals that different tasks put demands on the laboratory safety on different levels. Safety instructions have been of greater importance during chemistry working sessions than in biology. This may reflect an international trend, but it may be recommended, for several reasons, that the instructions for biology teachers should be developed further in this respect. It is of course important that the practical work of pupils is safe. Accidents do occur sometimes, but teachers should observe all practical precautions to prevent them. Equally important is the general educational aspect. When pupils already learn at a young age to observe safety regulations, they will probably follow safe working practices during their adult life. To observe the safety of other pupils in a school laboratory is equally important for similar reasons. It is also a part of the social skills of pupils.

5.3 Relevance to the problems of teacher education

It is very common that young teacher trainees are not able to analyze the pedagogical aspects of the classroom situations that they are requested to observe in the early phases of their education. The approach presented in this paper is valuable in structuring the observation in a manner that emphasizes those aspects of practical work that are central to the aims and goals. It is also essential that students taking different types of laboratory courses do not only practice technical skills, but also try to relate their work to the school curricula.

5.4 Implications to future research

We are working further on applied research, as well as on the research and development level, to create new practices the evaluation of the work in science laboratories in

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Finnish schools. It is important due to the need for providing more emphasis on the practical aspects of school work. On the other hand, we are going to collect wider observational data on practical work in sciences to be able to perform a more detailed analysis along the guidelines presented in this work. Our theoretical considerations may have further value in the analysis of teaching and learning situations in different school subjects as studied, for instance, within the FINISTE project associated with the National Board of General Education, Finland and UNESCO.

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Appendix 1

ımary of the laboratory work performed in the experimental groups

Experiment	Grade	Girls/ boys	Teacher´s opinion on the group	Instruction given by	Special indications for safety
Idenfication of subjects	8	0/12 7/7	average average	teacher and textbook	for chemicals
Lead and tin alloy	8	7/3 6/4	good good	teacher and textbook	for apparatus
Cell model	8	6/7 8/2	good average	teacher and textbook	no
Genetic code	9	8/2	average textbook	teacher and	no
Distillation	7	5/7 7/5	average good	teacher and textbook	for apparatus
Bacterial growht	8	5/6	average textbook	teacher and	for apparatus
Concrete and Portland cement	8	4/7	good	textbook	no

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Chemistry of carbon	8	7/5 0/12	good average	teacher and textbook	for apparatus
Crystal water	9	7/7	average	textbook	for apparatus
Redox potentials9		7/7	average	textbook	for apparatus
Moulds and soil investigations	8	6/4	average	textbook	no
Structure of cell 8		7/6	average	teacher and textbook	no
		103/109 Girls 49 %			

Appendix 2.

The laboratory tasks

The laboratory task # 1 was the identification of previously known chemical substances. The students were asked to identify six different substances (formic acid, ethanol, water, citric acid, and glycerol), which were in test tubes A to F. They were allowed to use all materials on the laboratory benches: ph indicator, zinc, tin, lead, hydrochloric acid. They could also ask the teacher for more materials. Here the freedom was being able to select from a number of alternatives. The teacher did not limit the freedom essentially, but since pupils did not have enough previous information and skills, they could not use their freedom. For task # 2 teacher gave short and clear instructions on how to prepare an alloy starting from pieces of lead and tin. Pupils heated the constituents, and studied the melting points as well as mechanical properties. Pupils had the possibility to compare their results with data in the literature. The instructions allowed a rather open-ended approach. Here the overall openness was on the same level than in the previous task. However, now the teachers role was somewhat more limiting.

Task # 3 was the construction of a cell model. The goal of this task was to become familiar with osmosis, which has an important role in all living organisms. The membranes of living cells are partially permeable, and thus osmosis is a ubiquitous phenomenon in cells. Pupils built up a cell model following instructions in their laboratory manual. The model was put into an iodate solution, and the membrane tension as ...s the change in the color of the solution was register-...structions in the textbook made the task closed.

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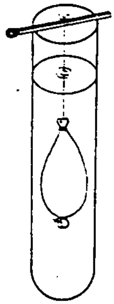
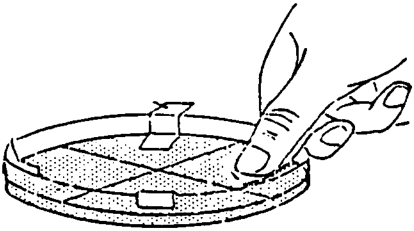


time	color in the tube	color in the cell model

Task # 4 was the study of a model of a genetic code. The hereditary characters, dominant or recessive, were simulated by throwing one or two coins. Heads meant a dominating characteristic, tails recessive characteristic (or vice versa). Pupils recorded their self-produced simulated data and compared the resulting probability with theory. The experiment may be considered unfair. The instructions given by the teacher made this task closed.

Task # 5 was purification by distillation. The teacher asked pupils to set up a distillation apparatus and to separate the components of a copper sulfate solution. There was a diagram of the distillation apparatus in the laboratory manual. After the experimental part pupils were to answer the following questions: How does the distillation apparatus operate? Study the distilled product. Is there still any copper sulfate? Where do the solid particles Tremain stay in the distillation process? The instructions were rather detailed, limiting the openness of this task.



The laboratory task # 6 was the study of bacterial growth. Students had to heat a nutrient substratum and to prepare a culture platter for bacterial growth under sterile conditions. Different specimens with bacterial contamination were put on the platter and growth rates were recorded during one week, working at home. Pupils had detailed instructions for this study in their textbook.

The laboratory task # 7 was the study of differences between concrete and Portland cement. The students were supposed to bring calcium sulfate and calcium carbonate in contact with water and study the properties of resultant materials. They had to find answers to three questions: 1) What is the difference between concrete and Portland cement? 2) Which chemical compounds form Portland cement? 3) How can we get calcium carbonate? The students had only a few possibilities for expressing or using their own ideas during this experiment.

Task # 8 was the study of structure compounds of different [illegible]nt cells. Students were instructed to take different

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plants and mosses through fresh preparations. Blue and iodax solutions were available to bring out the microstructures under a microscope. The experiment was closed due to detailed instructions.

The laboratory task # 9 was the study of the chemistry of carbon. The purpose of the experiment was to identify carbon in organic substances. Pupils were instructed to build, for this purpose, a test apparatus which can be seen in Figure 3 on page 26. Pupils heated organic material, usually a piece of wood, in the test tube. Pupils verified carbon from the distilled gases by different indicative reactions. Instructions for this laboratory task, as well as a diagram of the apparatus, were in their laboratory manual. They were also supposed to answer eight questions related to the experiment during or after the session.

Laboratory task # 10 was the study of crystalline water. Pupils determined the percentage of crystalline water in a crystal of copper sulfate by heating the crystal and measuring the loss of the mass by a good laboratory balance. They checked the result with theoretical information.

In task # 11 pupils used different pairs of metal electrodes, such as Cu and Mg, in an acid solution to measure the potential differences of metals by a voltmeter. They registered the voltage readings for each pair of electrodes and listed the metals in the order of relative potentials. The results were compared with data in the literature.

Task # 12 was performed in two parts. A spot of mold on bread was studied on different levels:by the naked eye, under a lens, and under a microscope. For the last level a slide pre- ation was required and the pupils were asked to study the microstructure. In the second part, soil samples were studied to search for living forms. The pupils were working on different levels of independence, some could not get free from instruction given by the teacher or in the laboratory handbook. However, a few pupils worked rather freely. Eventual species were identified by morphological similarity.

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A ix 3

The correlation matrix of different test items

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C2	-0.078											
C3	0.119	-0.061										
C4	-0.155	0.031	-0.070									
C5	0.064	0.129	0.090	0.031								
C6	-0.601	0.179	-0.203	0.132	0.253							
C7	0.045	-0.158	0.100	0.108	0.093	-0.033						
C8	0.098	0.465	0.300	0.463	0.491	0.354	0.322					
C9	-0.035	-0.140	-0.100	-0.002	0.075	-0.140	-0.013	-0.419				
C10	-0.086	-0.423	-0.267	-0.504	-0.580	-0.301	-0.344	-0.837	-0.146			
C11	0.078	0.253	0.019	0.094	0.175	0.109	0.107	0.322	-0.090	-0.297		
C12	-0.404	0.254	-0.169	0.133	0.373	0.611	-0.051	0.278	0.059	-0.338	0.119	
C13	0.008	-0.110	-0.070	-0.123	0.057	-0.024	-0.033	-0.165	0.161	0.083	0.068	0.021
C14	0.606	0.077	0.140	-0.048	0.105	-0.348	0.165	0.245	-0.139	-0.183	0.114	-0.192
C15	-0.183	0.071	-0.044	0.099	-0.039	0.142	-0.034	0.042	-0.045	-0.018	-0.088	-0.092
C16	0.194	0.339	-0.008	0.039	0.363	0.201	0.069	0.458	-0.142	-0.414	0.659	0.494
C17	-0.361	-0.245	-0.104	0.062	-0.078	0.087	0.009	-0.307	0.321	0.141	-0.372	0.067
C18	0.098	-0.188	0.107	-0.105	-0.373	-0.328	-0.094	-0.276	-0.125	0.376	-0.462	-0.669
C19	0.259	-0.089	0.123	0.244	0.043	-0.179	0.008	0.130	0.057	-0.176	-0.001	-0.063
C20	0.082	0.244	0.137	0.205	0.249	0.048	0.057	0.358	0.012	-0.398	0.067	0.221
C21	0.143	-0.268	-0.011	0.076	0.021	-0.230	0.433	-0.009	0.051	-0.021	0.088	0.029
C22	0.290	0.023	0.177	0.196	0.113	-0.143	0.194	0.323	-0.145	-0.264	0.068	0.012
C23	-0.137	-0.119	-0.077	0.134	0.119	-0.041	0.049	-0.169	0.484	-0.107	0.009	0.207
C24	-0.151	0.065	-0.097	-0.265	-0.183	0.152	-0.202	-0.156	-0.221	0.304	-0.065	-0.159
C25	0.156	-0.050	0.006	0.098	0.113	-0.161	0.265	0.116	0.011	-0.132	0.027	-0.015
C26	0.050	0.027	-0.105	-0.208	-0.028	-0.035	0.009	-0.066	-0.176	0.178	0.209	-0.058
C27	-0.161	0.093	-0.038	-0.225	-0.249	-0.020	-0.106	-0.185	-0.187	0.314	0.116	-0.055
C28	0.140	-0.033	0.040	0.257	0.332	0.002	0.319	0.344	-0.014	-0.366	-0.020	0.117
C29	-0.012	-0.024	-0.093	0.208	0.113	0.132	-0.072	0.122	-0.032	-0.113	0.039	0.042
C30	0.083	0.111	0.312	0.154	-0.032	-0.070	0.385	0.321	-0.042	-0.324	0.084	-0.109
C31	0.050	0.100	0.011	0.043	0.114	-0.028	0.218	0.205	-0.166	-0.124	0.247	0.036
C32	0.117	-0.231	-0.042	0.002	-0.044	-0.122	0.046	-0.143	0.119	0.084	-0.349	-0.116
C33	-0.155	0.076	0.022	-0.052	-0.095	0.133	-0.289	-0.118	0.092	0.073	0.005	0.055
C34	-0.717	0.208	-0.156	0.220	0.320	0.850	-0.091	0.288	-0.038	-0.291	0.080	0.656
C35	-0.236	0.271	-0.078	-0.184	-0.300	0.138	-0.355	-0.147	-0.209	0.286	0.182	-0.106

3	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
80											
77	-0.073										
26	0.441	-0.161									
0.041	-0.340	0.389	-0.600								
-0.316	-0.225	-0.165	-0.667	-0.195							
0.149	0.234	-0.003	0.104	0.003	-0.130						
0.116	0.159	-0.092	0.256	-0.033	-0.283	0.482					
0.118	0.173	-0.053	0.193	-0.106	-0.139	0.036	0.056				
0.161	0.341	-0.049	0.287	-0.178	-0.186	0.782	0.682	0.357			
0.057	-0.161	-0.055	-0.045	0.283	-0.208	-0.022	0.248	0.254	-0.205		
-0.179	-0.178	0.082	-0.215	-0.050	0.309	-0.656	-0.764	-0.489	-0.713	-0.541	
0.138	0.082	0.122	0.120	-0.103	-0.052	-0.012	0.098	0.264	0.146	-0.001	-0.124
0.056	0.070	-0.178	0.212	-0.337	0.054	-0.288	-0.119	0.014	-0.216	0.050	0.150
0.046	-0.024	0.050	0.062	-0.113	0.029	-0.168	-0.230	-0.095	-0.221	-0.040	0.219
0.054	0.190	0.189	0.126	0.096	-0.245	0.351	0.342	0.126	0.412	-0.022	-0.339
0.051	-0.017	0.510	-0.019	0.243	-0.203	0.124	-0.031	-0.042	0.055	-0.064	-0.001
-0.042	0.088	-0.015	0.026	-0.075	0.037	0.167	0.178	-0.083	0.180	-0.086	-0.093
0.133	0.139	0.177	0.279	-0.151	-0.202	0.053	0.089	0.117	0.135	-0.018	-0.103
-0.055	-0.048	-0.071	-0.269	0.076	0.259	-0.131	-0.040	-0.025	-0.115	-0.004	0.102
-0.108	-0.121	-0.145	-0.098	0.110	0.018	0.048	-0.070	-0.115	-0.060	0.024	0.034
-0.031	-0.416	0.136	0.136	0.212	-0.364	-0.176	0.051	-0.242	-0.205	0.105	0.101
-0.171	-0.125	-0.151	-0.043	-0.140	0.182	-0.253	-0.237	-0.414	-0.358	-0.158	0.420

	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34
26	0.042									
27	0.035	0.414								
28	0.482	-0.134	-0.198							
29	0.149	-0.308	-0.145	0.331						
30	0.048	0.071	0.023	0.293	0.060					
31	0.598	0.469	0.493	0.545	0.212	0.320				
32	0.126	-0.224	-0.412	-0.017	-0.117	-0.110	-0.531			
33	-0.794	-0.354	-0.225	-0.613	-0.147	-0.277	-0.711	-0.218		
34	-0.151	-0.024	0.012	0.073	0.123	-0.073	0.036	-0.190	0.116	
35	-0.470	0.220	0.451	-0.607	-0.256	0.010	-0.145	-0.285	0.403	0.107

Appendix 4
The list of variables

A. Practical skills
1. To show clearly full range of relevant manipulative skills
2. To appreciate the precision of the apparatus
3. To be able to obtain quantitative results within an expected range
4. To be able to perform the experiment within a reasonable time
5. To be able to modify the experimental plan creatively
6. To be able to carry out pilot experiments
7. To be able to carry out control experiments
8. Sum variable (0)
9. Sum variable (-1)
10. Sum variable (2)

B. General work habits
11 To be willing to work as a member of a team
12. To be willing to help in running the laboratory
13. To maintain constant attention and to work effectively
14. To be able to make suggestions for further research
15. Sum variable (0)
16. Sum variable (-1)
17. Sum variable (2)

C. Observation of laboratory safety
18. To follow safety instructions
19. To perform the experiments neatly and properly
20. To observe the safety of other pupils
21. Sum variable (0)
22. Sum variable (-1)
23. Sum variable (2)

D. Quality of experimental results
24. To interpret the data in the light of theory
25. To understand the accuracy and reliability of the data
26. To understand the meaning of the results
27. To be able to interpret properly the results of control experiments

28. To compare results with data from literature
29. To search for additional information
30. Sum variable (0)
31. Sum variable (-1)
32. Sum variable (2)
33. Schulman`s levels 1 2 3 4
34. Gender: boy 1, girl 2
35. Subjects: physics 1, chemistry 2 , biology 3

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Appendix 5

The Observation Form

School: Grade:
Teacher: Number of students:
Subject: Observer:
Topic:

2: pupils had achieved the objective
1: pupils had achieved the objective partly
-1: pupils had not achieved the objective
0: objective was not observed

A. Practical skills

1.	To show clearly full range of relevant manipulative skills	-1 0 1 2
2.	To appreciate the precision of the apparatus	-1 0 1 2
3.	To be able to obtain quantitative results within an expected range	-1 0 1 2
4.	To be able to perform the experiment within a reasonable time	-1 0 1 2
5.	To be able to modify the experimental plan creatively	-1 0 1 2
6.	To be able to carry out pilot experiments	-1 0 1 2
7.	To be able to carry out control experiments	-1 0 1 2

B. General work habits

9.	To be willing to work as a member of a team	-1 0 1 2
10.	To be willing to help in running the laboratory	-1 0 1 2
11.	To maintain constant attention and to work effectively	-1 0 1 2
12.	To be able to make suggestions for further research	-1 0 1 2

C. Observation of laboratory safety

13.	To follow safety instructions	-1 0 1 2
14.	To perform the experiments neatly and properly	-1 0 1 2
15.	To observe the safety of other pupils	-1 0 1 2

D. Quality of experimental results

16.	To interpret the data in the light of theory	-1 0 1 2
17.	To understand the accuracy and reliability of the data	-1 0 1 2
18.	To understand the meaning of the results	-1 0 1 2
19.	To be able to interpret properly the results of control experiments	-1 0 1 2
20.	To compare results with data from literature	-1 0 1 2
21.	To search for additional information	-1 0 1 2

Pupil follows the instructions given	by the teacher	
	in the book	
	by the teacher and in the book	
Pupil does not follow any instructions		
Special indications for safety	no	
	yes	chemicals
		apparatus
		outdoor activities
Teacher opinion on the class	good	
	average	
	weak	
Relevant skills expected	manipulative	
	work habits	
	safety	
	results	
	others	

Short summary of lab activity:

Further comments on pupils' actions:

Schulman's levels 1, 2, 3, 4

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