EXPERIMENTAL WORK IN FRESHMAN PROJECTS.

Jens Josephsen
Department of Life Sciences and Chemistry, Roskilde University,
P.O.Box 260, DK-4000 Roskilde, Denmark.

ABSTRACT

Forty-three student reports of their second first-year project period from the last two years have been analysed with respect to experimental work. A qualitative model of analysis listing 25 elements of experimental work in 4 groups have been devised. More than 40 % of the students have participated in experimental work of significance, while another 25 % of the students covered a less extensive number of the elements of such work in their projects. Still these projects contained relevant and necessary measurements and observations. The remaining students concentrated their efforts on other relevant learning objectives; some of these projects revealed a few elements of experimental work as well. The listing of elements might be used to guide students intending to do experimental projects.

INTRODUCTION

Introductory teaching in (natural) science subjects at the tertiary level cover theory, empirical facts, and experimental techniques. These major elements of science introduce the students
- to theories about nature, their elements and their structure,
- to facts about nature, of ways facts are organised, and of how to find facts in the literature, and
- to principles and performance of standard and advanced experimental methods of how to get answers about nature.

A great variety of experimental techniques and methods are available for teaching purposes. Still, the order of presentation of methods is normally dictated by tradition, by didactic considerations about safety and complexity, consumption of time, power of demonstration, and by economic factors as well.

At Roskilde University the situation is somewhat different relative to other Danish universities, because the curriculum takes a broader start through the college-like Basic Natural Science Programme (BNSP) lasting two years. In short, the BNSP is an open programme, which serves as a general introduction to science (and technology) as well as being the first part of several programmes leading to a master's degree in two science disciplines. Half of the programme is project-organised and problem-oriented, i.e. students, in groups, have to formulate a problem to be studied for a period. The other half of the programme is allotted to more or less traditional courses some of which have laboratory parts integrated.

The introduction to experimental techniques and measuring procedures is therefore not at all completed when the students try to find answers in the projects by doing experiments.

Thus the appearance of experimental techniques in the projects is governed by the problem under study (certainly within obvious limitations of availability, etc.).

EXPERIMENTAL WORK AND THE BASIC NATURAL SCIENCE PROGRAMME

Since experiment in science is so important it should be sufficiently emphasised in the curriculum. At present there are two points of regulation in the BNSP-curriculum:
Firstly, one of the projects has to "contain an empirical dimension being essential to the elucidation of the problem studied".
Secondly, the seconds of the two freshman-year projects are governed by the keywords: "Models, theories and experiments: The work have to demonstrate the use of theories and models, particularly the mathematical ones, within science. The interaction between models, experiments and theories, as well as the structure of the latter, has to be demonstrated.".
When considering the degree programmes of biology, chemistry, and physics, training in experimental work is most important. A proper introduction during the freshman-year is thus imperative.

The aim of the present study has been to analyse the second freshman-year projects with respect to the kind and degree of experimentation they represent. Experimental projects are often found to take place during the second year of the BNSP as well. The individual student might therefore very well have accomplished two projects providing insight into and skills of experimental methods and techniques.
Eight years ago a similar survey (1) revealed that the experimental work represented in the second freshman projects was not promising (seen from a chemistry tradition), while the mere existence of such experimental projects was the main concern twenty years ago (2).

EXPERIMENTAL WORK IN DIFFERENT TRADITIONS

Although the phrase "experimental work" appears in the curriculum text of the BNSP, there has been a lot of discussion about the definition of "experimental work". Normally, it is not a very important discussion within the tradition of a discipline.
Three factors make the discussion difficult, lively, and relevant for the optimisation of the teaching and learning environment of the BNSP.
Firstly, the BNSP serves as a general introduction to science and technology. The characteristics common to this area of knowledge have to be demonstrated clearly to the students during the course.
Secondly, BNSP serves as the first part of several science disciplines, at Roskilde University including mathematics, computer science, physics, chemistry, molecular and environmental biology, and geography. Obviously, the understanding of experimental work in these disciplines are very different, biology, chemistry, and physics being the disciplines most dependant on experimentation.
Thirdly, being problem-oriented, the project-work is in principle inter-disciplinary. There is accordingly not necessarily a normal science or generally accepted "do-as-usual" procedure.

Thus the resulting environment for teaching and learning "experimental work" within the BNSP is not very well defined. The continuing discussion of this issue is important and is in accord with the symbolic of the coral shell in the seal of the university. The text of the seal says "In tranquillo mors - in fluctu vita".

WHAT IS EXPERIMENTAL WORK

For the science disciplines it is important to distinguish between “real” experiments and simulation experiments. The latter use assumptions as input to a model, which - nowadays usually through a computer - gives an answer.
“Real” experimental work on the other hand, is characterised by manipulating, dissecting, controlling, and analysing isolated parts of nature. It normally includes observations and measurements.
The traditions in different science disciplines are of course very different. Thus in astronomy, ecology, and geology observation and measurements dominate for different reasons. On the other hand, in chemical synthesis and microbiology a lot of manipulations and many procedures will necessarily be included.

One could postulate that a proper general understanding of the significance of experimental work in science is only obtainable through the recognition of all such typical features of experimental work. Such a postulate would only have some validity in relation to students enrolled in the BNSP if typical features of experimental work can be defined more precisely and if there is sufficient time for it. In turn, this relies on the transferability of skills and comprehension obtained from an “archetype” of experimental work to other experimental situations.

Such general features have been described earlier (1) in three main groups of elements:

- -Design
- -Performance
- -Evaluation

or under a greater number of headings (3) describing the phases of experimental work:

- -Formulation of a purpose for the experimental work
- -Design of method and assembling of the equipment
- -Calibration, standardisation and obtaining data
- -Reproduction and calculation
- -Interpretation and comparison of results
- -Conclusion

Neither of these groups of headings are, however, sufficiently detailed to give non-scientists (as the students still are) an adequate guide to “the essentials of experimental work”. A more elaborate listing would be needed in addition to the oral guide from the actual project-supervisor.

The following listing is an attempt to give more details on the characteristics of experimental work grouped under only four obvious headings.

ELEMENTS OF EXPERIMENTAL WORK IN STUDENT PROJECTS	
A	**Objectives**
1	Definition of the purpose of the experiments
2	Suggestions for a possible outcome of experiments
3	Experiments suitable for elucidation of the validity of a hypothesis
B	**Design**
1	Use of standard equipment / standard instruments
2	Design of new fittings /accessories to modify the equipment
3	Use of standard procedures /techniques
4	Knowledge of more than one standard procedure /technique
5	Choice between several standard procedures /techniques
6	Knowledge of more than one method / principle
7	Choice between several methods / principles
8	Modification of an existing method / principle
9	Development of a new method / principle
C	**Performance**
1	Manual skills demanded by procedure / technique
2	Thoroughness demanded by procedure / technique
3	Time demanded by the complexity of procedure / technique
4	Calibration / standardisation / use of controls / sampling
5	Optimisation of procedure / technique
6	Reproduction of measurements / procedures
D	**Evaluation**
1	Knowledge of accuracy of method / technique used
2	Statistical analysis of data
3	Use of a mathematical model / fitting of parameters
4	Simulation of the results
5	Adequate presentation of the results / in accord with tradition
6	Comparison of results with existing knowledge
7	Interpretation of results with respect to hypothesis /purpose of the experiments

ASSESSMENT OF EXPERIMENTAL WORK IN STUDENT PROJECTS.

From a chemistry programme point of view the experimental training is very important. This has been one of the reasons to initiate an analysis of the experimental work as it appears in the project reports. As stated above, the second freshman-year project is governed by the keywords “Theory, models, and experiments”. The reports of these projects are obvious sources of study, because

- there are at least 20 to 30 reports from comparable groups of students at the same level each year
- the projects are likely to include experimental work because of the keywordsetting
- the reports reveal by and large the type and extent of experimental work made

In the 1989-survey (1) the analysis of the projects was only based upon the three main phases of experimental work: Design, performance, and evaluation. On this basis the projects were first categorised into two groups. One third of the reports did not contain experimental work of any significance. And although about two thirds of the reports

*"...contain some sort of observation and measurement, very few of these represent successful experimental work in the more elaborate sense. In too many cases, the practical work consists of a series of trivial observations of limited significance;..."(*1).

It should be mentioned that the reports revealed a lot of learning of science. Still, they were not very successful in the experimental work sense. Admittedly, the study was not very precise and the parameters of analysis were very rough. Accordingly the study was only presented as a *survey.*

The present study includes the efforts of 218 students (about half the number in each of the two spring terms 1996 and 1997) who in groups of 3 to 7 students wrote 43 reports. The volume of the reports amounted to on average 65 pages plus 20 pages of appendices, ranging from 30 pages to 160 pages in total.

Each report was looked over in order to learn what the subject and problem were and by what means the problems had been approached. Afterwards the report was analysed for the presence of each of the elements listed in the box "Elements of experimental work in student projects". Not necessarily all of the elements were expected to be represented in the individual work, but it was noted if one or more elements from each of the groups **A** to **D** were present and/or characterised the work most adequately. In the final assessment the individual elements were not weighted equally.

This procedure gave a fairly clear picture of the reports and it was easier to put them into two groups. The projects in the first group fulfilled the following criteria for being "Experimental projects":

1. The experiments have a certain volume amounting to at least 50 hours in the laboratory and/or in the field (corresponding to around 10 % of the total time)
2. The work deals with materials and phenomena in nature
3. The experiments contribute significantly to the elucidation of the problem studied

The second group of projects did not fulfil these criteria. This group contained 14 projects (5 in 1996 and 9 in 1997) and of these 6 projects revealed a few of the elements in groups **A** to **D.**

Among the first group of projects, "The experimental projects", there was a subgroup of 13 projects (6 in 1996 and 7 in 1997) where especially the Design elements were not represented very much. The procedures or techniques used in these projects were few and/or standard or - if the procedures or instruments were advanced - they did not document an independent discussion of design. This subgroup of "Observing and measurement"-projects had in several cases a solid theoretical part representing another important learning objective.

An example: A group of students investigated the orientation of coloured molecules (some of which were food additives) in a stretched polymer film as a function of the degree of stretching of the film. Furthermore they used the known stretching of DNA in a complicated (but existing and standardised) instrument to measure the possible binding of the food colorants to DNA. If they did bind they could be suspected of being potentially carcinogenic.

The other 17 projects (11 in 1996 and 6 in 1997) represented “experimental work” in the more elaborate sense, covering more elements of the Design phase category and revealing a large Performance phase.

An example: A group of students tried to evaluate different types of toothpaste with respect to their ability to remove hydrophobic coatings on teeth. They measured the surface tension in suspensions of the products and used three other techniques to quantify the power of removal of oily coatings. Two of these involved the use of genuine teeth. Standardisation was important in all experiments.

This result seems to be more promising from the experimental-work viewpoint when compared to the situation eight years ago. It might be a consequence of a more elaborate study guide (3) focusing on this essential aspect of natural science.

Besides being an instrument of analysis, the above listing of “Elements of experimental work in student projects” could be useful as a more elaborate guide for students being about to decide for an experimental project.

It is suggested that a proper exemplary experimental project within the natural sciences should contain most of the not mutually excluding elements of each of the above groups **A** to **D**. The word “exemplary” is seen in the term “the exemplary principle”. This principle can be understood as follows: skills and comprehension obtained in one particular learning situation can be transferred to another situation to such an extent that they build up qualifications or competence. The exemplary principle is thus analogous to induction from the special case to the general case. Obvious examples are manipulation skills and thoroughness that are desirable in all kinds of experimental work. Also, understanding the importance of safety precautions in one type of experiment can be generalised. A proper combination of respect and sound scepticism towards numbers in tables and empirical facts is likewise a qualification to be build up.
We believe in and rely on such a transfer mechanism in the experimental science disciplines and are therefore very concerned about proper experimental work during the BNSP.

(1) J.Josephsen, "What is Science - according to the freshman students", in V. Meisalo and H. Kuitunen (eds.) Innovations in Science and Technology Education , National Board of General Education, Helsinki, 1990, p.287-290

(2) J.Josephsen, "Is it possible to carry out research-like experimental projects with first year university students within the basic natural science programme?", in M.Cornwall, F.Schmithals and D.Jacques (Eds.)," Project-Orientation in Higher Education. Proceedings of the International Seminar Project-orientation in Higher Education in Science, University of Bremen, March 1976." Brighton Polytechnic and University Teaching Methods Unit, University of London 1977, p.130-131

(3) J.Josephsen et al. (eds.) Håndbog. Naturvidenskabelig Basisuddannelse. Studievejledning, Roskilde Universitetscenter, 1994, p.44