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EXPERIMENTAL TRAINING FOR CHEMISTRY STUDENTS: DOES EXPERIMENTAL EXPERIENCE FROM THE GENERAL SCIENCES CONTRIBUTE?

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ABSTRACT: Project reports from 132 second semester freshman students of the Natural Sciences Basic Studies programme at Roskilde University were analysed. These 15 ECTS-point problem-oriented projects should illustrate, by an example, the theme "Models, theories and experiments in science", and are chosen by the students within or across borders of the classical university subjects. The present analysis focuses on the elements of experimental work performed and reported by the students. Two assessment tools were used: The one refers to classical types of chemical experimentation; the other is formulated in broad categories of elements of experimental work, which is common to all of the natural sciences in order to embrace all different traditions of "good scientific performance". The reports witness little of the central types of practical work traditionally associated with chemistry, but much experimental experience which can be considered relevant to training in chemistry. It is argued that experimental activities not included in the traditional chemistry curriculum may contribute to the formation of a "good chemist", and that broad entrance programmes may attract more students to chemistry. [*Chem. Educ. Res. Pract.*: 2003, *4*, 205-218]

KEY WORDS: *experimental experience; general science experiments; problem orientation; project work; freshman projects.*

INTRODUCTION

The relative decline in enrolment of students in chemistry, physics and mathematics over the last decades is a factor of current concern, which seems to influence curriculum development. The trend in Denmark is that the freshman students are invited into broader science programmes rather than into the single subject (such as chemistry or physics etc.) only. Such programmes should minimise the waste of time for students who change their minds on their favourite subject. If a student intends to graduate in, say physics, and after some time (typically more than one year) decides to change to chemistry, then he or she used to have to start form scratch in chemistry. Slow graduation rates and large drop out numbers have for a long time been a significant problem in Denmark in science and mathematics. Such broad entrance programmes may enhance the number of students who actually choose the physical sciences and mathematics and lead to a decrease in the number of students dropping out (EVA 1998). At Roskilde University a two years Natural Sciences Basic Studies programme (the NSBS-programme) is offered. The programme is unusual in introducing students' projects from the very beginning: the students choose among a variety of different, more or less conventional science and mathematics courses, and half of the time they work with problem oriented projects - one each semester - in groups (Josephsen 2000). With the two first years of studies complete, the student takes two subjects for a B.Sc., and they normally continue for a M.Sc.[1] with the same two subjects, one of which could be chemistry. Therefore the NSBS programme also functions as the first part of the chemistry programme for those students who choose chemistry. Accordingly, the type and extent of qualifications relevant to chemistry obtained during the two first years should be mapped in order to optimise the chemistry course, which follow the NSBS-programme. This is the concern of the present study, with special focus on which experimental aspects of chemistry *may be* experienced through this type of project-organised programmes. The findings from such an analysis may contribute to curriculum development.

Why so much focus on laboratory work in the curriculum?

Practical work is a characteristic element in science teaching at all levels. In tertiary education a chemistry curriculum without experimental work is unthinkable. It would be generally accepted that laboratory training covering the manipulation of a great variety of equipment, a whole range of simple and more advanced measuring techniques, the safe and clever handling of both relatively innocuous and dangerous chemicals, and the separation and purification of synthesis products are part of every chemistry graduate's experience. But this present study is informed by a number of questions:

- What is an appropriate mix of such elements, how little is enough, and what is essential?
- Are experiments in physics, the life sciences, or the earth sciences totally different from those performed "in chemistry", or to what extent do they overlap?
- Could experience from one teaching subject replace training in the other?

An analysis of the elements of experimental work in chemistry and in the general sciences could be a tool when discussing such questions.

Intuitively, to most science teachers it appears justified to include practical work, because observation and manipulation of isolated elements of "the physical world" is part of the very nature of science. But is the purpose of getting experimental experience so obvious that we do not need to define it further?

In a recent study Woolnough (1998) compared the English physics teachers' views of the role of experiments and practical work in teaching over the last 30 years. It was shown that while the aims supporting understanding and illustration of theory were ranked high in the beginning of the period, the process aims (e.g. "to practice seeing problems and seeking ways to solve them") were later regarded as more important.

Several workers (Woolnough 1983, Kirschner, 1992, White 1996) have analysed such often held views on the role of experiments and practical work in school and argue that experimental and practical work in school should be included if it allows the learner to:

1. Practice skills (through exercises), i.e.

    - to observe and measure;
    - to manipulate equipment;
    - to plan (or design) experiments;
    - to interpret results;
    - to communicate about experimental work.

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[1] In Denmark the M.Sc. (5 years) used to be the first degree. Only recently the European 3+2+3 degree structure has been implemented at the universities, but is still not much recognised by students, by staff or in society.

2. Practice academic processes (through investigations), i.e.

- to identify a problem;
- to reformulate a problem;
- to design strategies for its solution;
- to choose a strategy for its solution;
- to solve the problem;
- to evaluate the solution.

3. acquire experience with phenomena and materials (through activities with much observation and manipulation), which gradually accumulates as tacit knowledge or Fingerspitzengefühl (German for Feeling at the finger tips).

At university level it may seem more obvious to include experimental and practical work, and the above roles, i.e. to "practice skills", "practice academic processes", and "acquire experience with phenomena", are indeed highly relevant. In an extensive EU-study (Welzel *et al* 1998) of the role of "labwork", upper secondary school teachers and university teachers (with respect to the first two years of teaching) were asked to rank the following 5 objectives:

a) for the student to link theory and practice;
b) for the student to learn experimental skills;
c) for the student to get to know the methods of scientific thinking;
d) for the student for foster motivation, personal development, social competency;
e) for the teacher to evaluate the knowledge of the students.

The study showed that "to link theory and practice" is ranked highest among European university-teachers and that the two process-oriented objectives B and C were regarded as almost equally as important. Apparently, many university teachers (as well as those from secondary school) in Europe believe that linking theory and practice is facilitated through experimental and practical work in teaching. The teachers were also asked to consider how the link between theory and practice was established. Given 12 different formulations, they pointed at "understanding of theory" as most important. Formulations approaching "acquire experience of phenomena" (cf. 3. above), e.g. "make phenomena occur", were not considered as important. Further, the university teachers recognise the importance of labwork as the means for obtaining laboratory skills and practising academic processes. (cf. 1. and 2. above). Apparently, this European study does not perfectly agree with Woolnough's study (1998) on the importance of the "understanding of theory" role of experiments. There might, however, not be sufficient evidence that experimental work fulfils all the roles, that many teachers believe it has (White 1996).

Hodson (1992), by formulating three different aspects in science education "learning science, learning about science, and doing science" points at different roles for different types of experimental work. This is also evident from the title of Woolnough's (1983) paper "Exercises, Investigations, and Experiences", and Hodson (1993) discusses in detail how different types of practical and experimental work may have different aims and serve different purposes. This perspective was included in the EU study (Welzel *et al* 1998) by asking the teachers, which type of "labwork" were useful for bringing about the 5 objectives A-E. The labwork was divided into 1. demonstration experiments, 2. experiments carried out by the students, 3. open ended labwork, 4. strongly guided labwork, and 5. experiments using modern technologies. The teachers responded, that experiments performed by the students (type 2) were "useful to reach all objectives", that demonstration experiments (type 1) were "useful to link theory and practice", and that strongly guided labwork was "useful to develop experimental skills". In spite of the lack of evidence that all of these beliefs are true, in more recent years the different roles of different types of experimental and practical work (c.f. Woolnough 1983, Hodson 1992, 1993) have been recognised more at university level (Millar *et al* 1998 and 1999, Domin 1999, Hunter *et al* 2000, Johnstone and Al-Shuaili 2001, Byers 2002). It appears as if teachers in the universities have begun to learn from the school level discussion, which might be helpful to any science teaching under changing conditions.

This type of research focuses on teaching and the teachers' perspectives, i.e. the intended goals (*the matter meant*), and relates much to an instructional tradition. As has been thoroughly analysed by Millar *et al* (1998 and 1999) it is a question to what extent the actual teaching (*the matter taught*) leads to the desired development of students' knowledge, skills and competencies (*the matter learned*). Also, White (1996) stresses the point, that the students have to be (mentally) engaged in the laboratory to learn anything from it. Ultimately, the important thing is what the students actually learn and are able to do, and which problems they are able to solve.

From the perspective of the set curriculum, the discrepancy between *the matter meant* and *the matter learned* is a serious problem. The constructivist approach recognises that the student has to take the lead in bringing about learning. Investigation-type elements in the curriculum may be a vehicle for getting experimental experience integrated within a context, in contrast to experience related to a syllabus. The assessment of students' performance during problem-oriented project work in a general science programme may elucidate such questions as how does this work at the introductory university level, and does it facilitate relevant learning?

It is possible to study and describe the experimental experience that may be obtained (*the matter meant*) through the courses of a programme on the basis of written instructions in lab-manuals etc. In contrast, the type and extent of experimental work in the students' projects at this university is fairly unpredictable due to the very nature of problem-oriented projects. A description of the experimental work can only be based on what the students actually do during their projects. The practical source of knowledge of what happened is the written project reports, which the students present and defend like a thesis at the end of each semester. The result of such an analysis may be closer to what has been learned (*the matter learned*) than what can be extracted from written laboratory instructions etc.

For the second semester of the freshman year, the students are asked to choose and define a problem through which they can explore the nature of and relationships between "Models, Theories, and Experiments in Science". It is therefore likely, that this second freshman project actually has experimental work as an important component. In the study reported here, project reports from 132 first-year students in their second semester (spring 2000) were analysed with respect to the experimental contents from a chemistry as well as from a general science point of view (Josephsen 2001).

UNFOLDING EXPERIMENTAL WORK IN THE SCIENCES

The characterisation of experimental work depends on the context. Hellingman (1982) lists "abilities required for practical work" in chemistry, physics and biology to be assessed in practical tests in Holland. The chemistry list is very detailed and contains 63 elements in 4 categories (*preparation for an experiment; performing the experiment; elaboration of the observations; and account for activities and results*). Since the lists for physics and biology contain a majority of the same elements, it is tempting to take this as supporting the view, that experience from one of the three subjects might be useful in the other subjects. The same emphasis on the generality of elements of experimental work in science (Josephsen, 1997) was the basis of an earlier analysis of freshman project reports with respect to experimental work. The specification of 25 elements grouped in 4 categories (Purpose, Design, Performance, and Evaluation) is a representation of experimental work, which is quite similar to the above lists from Holland (Hellingman, 1982), although it highlights the *design elements* by putting them into their own category: *Design*. This might be a consequence of (the level and) different expectations of the students' creativity in the choice of techniques and methods. Rather than being a refined instrument of assessment, a detailed list of elements of experimental work was suggested (Josephsen, 1997) to function as a guide for the students to check for themselves if they have considered the experimental work in sufficient detail during their project. Also, Garratt (2002) stresses the importance of the "thinking" part of experimental work and lists six steps. The first three steps in his scheme, (to *decide* what to observe; to *imagine* the conditions for observing; and to *plan* how to create these conditions) may be considered as another formulation of "Preparation for an experiment" (Hellingman 1982) and of "Purpose" + "Design" (Josephsen, 1997). At university level such elements of experimental work should play a significant role in the formation of an "experimental scientist" (Garratt, 2002). These approaches point at general academic and general science qualifications.

Turning attention to the characteristics of typical experimental work in chemistry, there are experiences which are not covered by (the study of) any other science subject. The detailed lists of "abilities required for practical work" (Hellingman, 1982) are formulated in a language which is very "manipulation" oriented (e.g. ‘record the correct number of decimals’ or ‘manipulate glassware’). This leaves little impression of the characteristics of what you do and experience in a chemical laboratory (e.g. how does the red colour of the indicator appear on the final drop of sodium hydroxide? Or how does the potentiometer reading stabilise when the rinsed electrodes are immersed into the carefully prepared, stirred solutions of a suitable standard compound to give valid data for a standard curve. Or, how do you weigh out and transfer a sample of the beautiful, dry crystals of your synthesis product to a measuring flask, etc.). To deal with detailed descriptions of such characteristic elements in the chemical laboratory in a comprehensive way would be very difficult, if not impossible. For example, in Vogel's classic "Practical organic chemistry" (1956), the index reveals at least 65 different techniques and operations besides the large number of types of preparation and analytical techniques. Broader categories than this are obviously more appropriate. The use of titles of conventional laboratory courses doesn't offer much help either. "Analytical chemistry", "Synthesis", and "Spectroscopy" are broad categories, but "Experiments in physical chemistry" seems to belong to a different logic (and could include spectroscopy and analytical techniques as well).

"**Chemical substance**" is a key concept in chemistry, and experimental work in chemistry invariably includes the handling of chemical substances with a given purpose. So a clue towards defining useful categories may be the purpose with which one handles chemical substances in a laboratory. This “handling” always includes the consideration of design and safety issues, apart from the careful performance of the experiment itself. "The *composition* of matter, materials and chemical substances, how to *change* them into others, and their chemical and physical *properties*" is a brief extract of what chemistry is about according to a number of contemporary general chemistry textbooks (in English) on the lecturer's shelf. It is, of course a matter of taste (and purpose) how to reformulate this extract under a limited number of headings. In Table 1, six types of chemical experimentation grouped according to their purpose are presented. They represent one way of expanding "chemical experimentation" in a few categories, which are easily identified in any written material, describing performed experiments. These types are central and typical in any chemistry programme (but, admittedly, not equally important, when considering how much time should be spent on each of them), and could be considered as a more or less exhaustive,

TABLE 1. *Types of chemical experimentation, each of which has a dimension of safety and design.*

Type	Purpose of activity
Synthesis	to devise and control a chemical reaction to give an intended **chemical substance** (an intended formation of a chemical bond)
Separation	to isolate a particular **pure substance** or group of substances from a mixture
Detection	to prove the presence of a particular pure **chemical substance** or component in a sample
Quantification	to show how much of a given **chemical substance** or component is present in a sample
Identification	to demonstrate the identity/stoichiometry of a particular **chemical substance** or a well-defined mixture of substances
Characterisation	to determine a particular qualitative or quantitative property of a pure **chemical substance,** a component, or a well-defined mixture of substances

though not detailed, list of practical business in chemistry. It is fairly easy to read from a project report (which is not simply a report of a lab exercise) whether or not - or to what extent - chemical substances or mixtures have been handled in a way a chemist (or a chemistry student) could have done, i.e. with a purpose typical to chemistry (cf. the types given in Table 1). Since the analysis is qualitative it is of minor importance that the types of Table 1 are not equally important in a chemistry program, if importance is measured as study load. For example, "Characterisation" is a very broad category representing a great variety of quite different principles and techniques, and the students spend much time during their first chemistry degree programmes by characterising different chemical substances in different ways. Still, it is fair to suggest that the types listed above qualitatively embrace what might happen in a laboratory with chemistry students.

EXPERIENCE WITH CHEMICAL EXPERIMENTATION

In their second semester the first-year students work in project groups in which they define and study problems illustrating the theme "Models, Theories, and Experiments in Science". At the end of the semester, the students write up a project report, which has an abstract and normally an "Experimental" or a "Materials and methods" section. A report describes typically through 65 pages (A4-format) the problem studied, and includes an account of where the problem originates, in which respect it is a problem that can be studied or solved by science methods, and which larger question it is part of. The 25 project reports produced by one of the latest population of such students[2] were used as the object in this study. The actual students were chosen only because they were the most recent ones when the study was initiated, and there is no reason to believe that this sample of students is not typical for our students of these years. The reports were labelled according to an area of teaching and research at the university (see Table 2) and analysed from a chemistry point of view, looking for evidence of experimental work of one or more of the above six types (cf. Table 1). It turned out to be a fairly easy task to extract the essentials of the students' work in the laboratory. For a senior university experimental chemist it is obviously not difficult

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[2] NSBS students enrolled September 1999 performed their second project in 25 groups of on average 5.2 students during the spring term 2000. Such a project corresponds to half of the study load for one half year - 15 ECTS-points (European course Credit Transfer System).

qualitatively to analyse and categorise reported experimental work into the six types of Table 1 even if the work is more physics or biology than chemistry.

The results of the analysis of the project reports with respect to typical experimental work in chemistry are summarised in Table 2. In the two first columns, the chemistry words are highlighted. The last six columns refer to the types of chemical experimentation.

As is seen from Table 2 and represented also in Figure 1, the central types of experimentation in chemistry seem not to have been important in many of the actual projects. The analysis also showed that:

1. Techniques of analytical chemistry to separate and quantify chemical substances were used in one third of the projects.

This is not an unexpected finding, since analytical chemistry techniques are powerful routine tools for the solution of many problems in e.g. medicine, environment, and technology. Experience with such procedures is essential training for a chemistry student (as well as for many others). However, a pitfall may be that the procedures and techniques are used as standard-methods in any sense, leaving little room for considering the design of an analytical method. Indeed, in most cases the students seem to have adopted and used only standard procedures without further deliberation. They may have been engaged in choosing among more methods and techniques, but this is typically not described in the report. Furthermore, discussions of the safety issues of these experiments were fairly limited.

2. Synthesis is not part of any of these projects.

The synthesis of model compounds (not available commercially or at a reasonable cost) and the study a structure-activity relationship would be a way to elucidate "Models, theories and experiments". That this type of work is rare is not surprising, since it would probably be a very difficult job for first year students, without experience from a synthesis course.

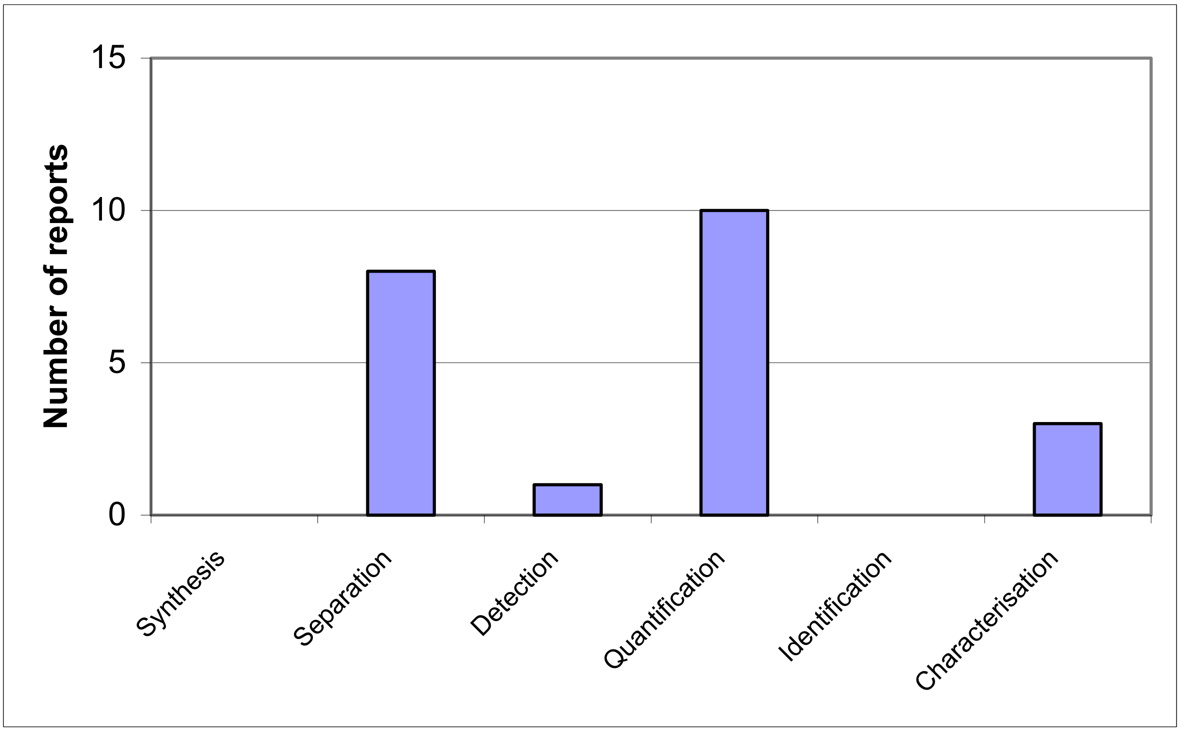

FIGURE 1. *Distribution of reports among various types of chemical experimentation.*

TABLE 2: *25 Reports from 132 students.*

Title/area of study	Area of study	O1	O2	D1	D2	E1	E2	R1	R2	I1	I2	SYN	SEP	DET	QUA	IDE	CHA
The dynamics of the boomerang	Aerodynamics	+		+	+	+	+	+	+	+							
Restoration of Lake Borup	Aquatic ecology					+	+		+				+		+		
Classification of Danish freshwater streams by micro invertebrates	Aquatic ecology	+							+								
Fauna analysis of watercourses. An evaluation of the environmental status of X before and after restoration	Aquatic ecology	+				+	+	+			+						
Monitoring ponds	Aquatic ecology	+						+			+				+		
Unilamellar vesicles	Biophysical chemistry	+		+	+			+	+		+		+				
Protein folding monitored by IR-spectroscopy	Biophysical chemistry	+	+	+		+				+	+						+
UV radiation of Tardigrades in cryptobiosis	Biophysics	+	+	+	+	+	+			+	+						
The neuro impulse as a function of temperature	Biophysics	+	+		+	+		+							+		
Transient chaos in a closed Belousov-Zhabotinsky reaction	Chemical kinetics	+	+				+		+						+		+
Albedo in the desertification in the Sahel	Climatology	+			+	+			+								
Implementation of different sorting algorithms in different computer environments	Computer science	+	+	+	+	+	+										
Automatic categorisation of home pages	Computer science	+		+	+			+									
Hedgerows in biological pest control	Conservation biology	+				+	+			+							
The [Cu] in sediments due to antifouling	Environmental chemistry	+	+			+	+	+	+	+			+		+		
Flow direction in a closed elastic circuit	Fluid dynamics	+		+	+	+	+	+	+	+	+						
Alcohol and the nervous system	Human physiology	+			+	+		+			+		+		+		
Natural microbiological degradation of oil	Microbiology	+		+	+						+						
Yeast test of oestrogen-like compounds in plastics	Molecular biology	+	+		+	+	+		+		+		+		+		
The treatment of cancer cell lines with platinum drugs	Molecular biology	+				+								+			
Coloured shadows	Optics/colour vision	+	+	+	+	+	+	+	+								
Equilibrium for a charge transfer complex	Physical chemistry	+					+	+									+
The migration of metal ions in soil	Soil science	+			+	+	+				+		+		+		
Roundup in different soils	Soil Science	+	+	+	+	+			+		+		+		+		
The retention of nitrate in soil	Soil Science	+				+							+		+		

Titles, areas and general and chemical experimental experience. Headings 3-12 refer to the 5 categories Objectives (O1, O2), Design (D1, D2), Experimental (E1, E2), Results (R1, R2), and Interpretation (I1, I2) as outlined further in the text. Headings 13-18 refer to the 6 types of chemical experimentation: Synthesis (SYN), Separation (SEP), Detection (DET), Quantification (QUA), Identification (IDE), and Characterisation (CHA) of Table 1.

3. Although "characterisation" of chemical substances or well-defined mixtures is a very broad category it was found only in a small number of project reports.

Only very few projects witness the handling of chemical compounds, and among those only a few project groups seem to have *studied* the compounds. In the other cases they were just *used* in procedures to learn about other objects. The students seemed not to have been deeply engaged intellectually in the design of the method of characterisation and not much safety consideration seemed to be considered necessary in these cases either.

The analysis shows, that the second first year project of the NSBS programme only provided training of the central experimental types in chemistry for a few students.

Although many of these students followed an organic chemistry course with labs in identification, the experimental training obtained through their project work would apparently not add up to the same as those following a chemistry degree programme from day one. We need to ask, therefore, whether this implies that a general science entrance (which allows students some choice of the subjects for study in their projects) at the university impairs the conditions of making a good chemist?

The answer is *yes*, if experimental experience from other fields of science has nothing in common with the types of experimental work, which are *central* to chemistry. For those who refer to a conventional university programme (in ‘the good old days’), this might very well be the obvious answer.

The answer is, however, *no*, if the students, like those students who have changed to chemistry from another science subject, experience experimental work which is *relevant* to experimental chemistry from other fields of science. This answer presupposes that specific training in experimental chemistry will be a significant component for those who specialise in chemistry after the general science programme. In the actual case, this is certainly true.

As is already suggested above by comparing objectives lists from physics, chemistry and biology (Hellingman 1982), it is the underlying hypothesis behind this study, that some elements are common to several of the different branches in science. One might talk about a certain transfer value of experimental experience from one tradition in science to another, especially if the type of experience is of a fundamental character related to observation, measurement and experimentation. Obviously other categories than those above “from inside chemistry” should be applied to elucidate the validity of this hypothesis.

THE GENERAL SCIENCE PERSPECTIVE

Therefore the same reports were analysed from a general-science point of view. Five fairly general categories of most scientific experimental work (Objectives, Design, Experimental, Results and Interpretation) were used as a template. These five categories represent a slight rearrangement and reformulation of the above expansion of Woolnough’s (1983) "investigation"-type of practical work and of the discussed lists of elements of experimental work in the sciences (Hellingman 1982, Josephsen 1997, Garratt 2002). The general formulation was intended to allow for a fair assessment of activities from quite different traditions of observation and experimentation that is characteristic of the different natural science disciplines:

1 The formulation of **OBJECTIVES** for the investigation:

O1 Reasons for studying the particular question in detail.
O2 Accounts of possible outcomes and expected results.

2 Choice and **DESIGN** of methods and equipment:

- **D1** Choice and design of principle of investigation.
- **D2** Choice of standard techniques or a new design.

3 **EXPERIMENTAL**:

- **E1** Standardisation, optimisation, calibration, safety measures.
- **E2** Reproduction of procedures and measurements.

4 **RESULTS:**

- **R1** Evaluation of accuracy and precision.
- **R2** Processing and presentation of data.

5 **INTERPRETATION** and discussion:

- **I1** Comparison of results with expectations.
- **I2** Fitting of results into existing knowledge.

The analysis focused on which of the five categories seemed to have provided intellectual challenge to the students. As evidence for this the report should discuss *how* the particular feature is handled and *why* the actual handling was chosen. At best this discussion should refer to the (international) literature. When not discussed it was anticipated that the way of handling was mostly due to the supervising teacher and taken for granted by the students. The assessment was not graded, since the study is preliminary and the method of analysis was actually on trial. The analysis of all the reports was repeated with a month or more between the first and second time to check the reliability of the approach.

GENERAL EXPERIMENTAL EXPERIENCE

The results of the analysis with respect to general experimental experience are summarised in Table 2. The titles of the project reports are given in column 1. The title is normally significant and gives together with an abstract a fair description of the problem studied. In the second column the area of study is characterised roughly according to which sub discipline it may belong. The next ten columns refer to whether or not each of the above (Objectives, Design, Experimental, Results and Interpretation) elements was dealt with in the reports according to the above criteria.

Some trends can be extracted from Table 2:

1. The practical work described in the reports seemed in almost all cases to be relevant to the problem formulated, and also took literature findings into account.

Since the second semester heading is "Models, theories, and experiments in Science", it is not an unexpected finding, that practical work was an integral part of the project from the beginning for the vast majority of groups. A few projects are based mostly on a single reference in literature, where an experimental result may have been limited, uncertain, or inaccurate. Thus the main aim was to reproduce and extend such investigations under specified conditions and to get new or better results. A driving force for the students to include practical work in the projects is to solve a problem which has not been solved before. This is in contrast to most ordinary first year "practicals" and exercises in the laboratory, where the result of the experiment is known (by the teacher) or could be looked up in a book or in the literature, and is of no use *per se*.

2. Only one third of the reports explicitly discuss the possible outcomes (results) of the experiments, although in some cases this aspect was implicit in the arguments for performing the practical work.

The students are offered written instructions for setting up and formulating their reports. In this guide it is not underlined that it is useful to set out one's expectations or predictions on print. Reading ‘between the lines’ in the reports shows that such considerations have not been absent, but their role in designing the methods or specifying the conditions is not made clear.

3. About half of the project groups seemed to have adopted a standard experimental technique (or combination of techniques) and to have used a straightforward principle of investigation without further arguments. In the other half of the cases different possible methods have been (more or less thoroughly) discussed and criteria for preferring one to the other have been given.

This feature undoubtedly reflects the quite different number of available standards normally used in different scientific fields. For example, in experimental physics a specially designed method is often used; such experiments are not burdened by time consuming standard techniques, requiring skilled performance, as many molecular biology investigations are. In chemistry both extremes are represented.

4. Two thirds of the reports showed that standardisation/calibration procedures and safety measures have been addressed in some way or another and that the principle of replicating results had been followed.

When considering that a great fraction of the actual practical work couldn't have been done without using standard procedures with built in standardisation/calibration the fraction of 2/3 ought to be higher.

5. The evaluation of accuracy and precision of results and further processing of data may be more relevant in some cases than in others. It was found only in about half of the reports.

It is obvious that this aspect is important in analytical chemistry and other fields, where numbers are to be compared with numbers from other studies and where conclusions are based on such comparisons. In other types of chemistry the accuracy is not necessarily the most import thing. This was not studied further.

6. The general lack of comparison of results with expectations is consistent with the above finding that such expectations were often not formulated explicitly in the first place (cf. 2. above).

7. Half of the reports revealed a proper discussion of the results obtained in relation to existing knowledge available in the literature.

Investigations by freshman students seldom produce "water proof" and publishable results right away. Some are actually not very conclusive. The discussion of results in relation to literature is not easy in such cases, and one of the bad habits from school, to list a lot of possible sources of systematic and random errors instead, was seen in some cases.

8. Advanced safety issues were not relevant for many of the projects.

This finding is consistent with the absence of safety alert information often found in chemistry such as organic synthesis, radio tracer studies, extraction procedures using ethers, the handling of explosive or highly flammable chemicals etc. For the projects using assays with mutagens (cf. Table 2) such tests followed the routine safety procedures.

Most of the projects were "single-subject" projects, where the problem studied matched the expertise of the supervising teacher rather well. The projects identified as "chemistry projects" seemed in the first place not to reveal better general experimental training in the above sense than the average. As a matter of fact, some of the other projects seemed qualitatively to have covered the 10 elements of Table 2 more extensively.

To summarise, these first year projects as a whole represent a fair coverage of the five categories of experimental work at undergraduate level which include both practical skills and other "skills needed by the experimental scientist" (Garratt 2002). However, there were also found substantial differences; e.g., some groups apparently followed established standard procedures (e.g. classification of Danish freshwater streams; equilibrium for a charge transfer complex; the treatment of cancer cell lines with platinum drugs; c.f. Table 2). These students did not document whether they had considered how to design the experimental investigation; instead they may have concentrated on understanding and performing the standard procedures.

CONCLUSION

The study has shown that the second first year project of the NSBS programme does indeed contribute to the training in practical work. A major fraction of the students get experimental training, which is of *general* relevance to chemistry (as well as to the other natural sciences). In addition, the experimental training obtained during the student projects includes aspects of experimental work not normally present in introductory university laboratory exercises where students follow recipes. In particular, the purpose and design of an experimental investigation play a significant role for our students. The assessment of what the students in a group have achieved through their project is based upon the report and a "defence" session with the supervising teacher and another staff member as opponents. During this evaluation session weak points in the investigation, including its experimental procedure, is discussed. Apart from serving assessment purposes, this discussion is intended to have the students learn from their shortcomings and use this experience in their further course of study. It is our experience (which is not documented by the present study) that the students indeed improve their performance in the following projects.

Broad entrance programmes in science may be seen as a way to attract more students who are not sure about their favourite subject. From a traditional point of view this could be regarded as a delay of the "real" start of university studies, because the first period will be less dedicated to the single subject. Indeed, this type of attitude was prevalent around 20 years ago, when evaluation of programmes was young in Denmark. As seen above, the analysis of a general programme with a traditional "chemistry" ruler may not give a fair picture of what has been learned of relevance to chemistry, if the strict chemistry content is modest. On the contrary, a broad entrance programme should aim at other objectives not formulated in syllabus terms. These objectives could be divided into:

A. General academic objectives (not including practical work)
B. General natural science objectives (including practical work)

C. Special objectives including supporting subjects (e.g. mathematics) and basic training in the subject (e.g. chemistry).

This gives the students the possibility of exploring different subjects at university level before making their final decision of a specialism. We experience a growing interest in chemistry during our general science entrance programme and it turns out that the choice of a degree programme combining chemistry with either environmental biology or molecular biology is rather popular. Out of the 132 first year students of this study, 104 passed the first two years. 91 students went on to the third year, entering the subject programmes. Of these 25 did choose chemistry, a number exceeding the number of students in the "chemistry"-projects in their second semester (20 students in the 5 groups, cf. Table 2). An extra recruitment apparently takes place as suggested (EVA 1998). The chemistry programme itself includes an extensive experimental dimension, benefiting from the general experimental experience obtained through the two first years at the university.

In conclusion, there are different possible foci for an analysis of which experiences and skills students have acquired from their previous course of study. If the focus is too narrow and single-subject centred it may obscure what students have been prepared to do in a general way and are able to do in the single subject - in this case chemistry. If the elements of training which are common to the sciences are recognised, the subsequent chemistry teaching could benefit from them and concentrate more on those elements which are special to chemistry. When considering the experimental dimension in university training this is not less true.

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