TEACHING AND LEARNING TECHNIQUES IN SECONDARY SCHOOL SCIENCE EDUCATION USING A TECHNO-SCIENCE CONTEXT OF INDUSTRIAL TECHNOLOGICAL PROBLEMS

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Abstract

In support of the title of this thesis, an historical review of the literature and methods of delivering practical work in science in secondary schools was carried out. From the work of others, a personal model of classroom scientific investigations was developed and formulated in terms which could be tested in schools.

The main emphasis was to see

(a) whether the educational value of the model for practical investigations set in a context of integrated science and technology ('techno-science') could be defended theoretically and demonstrated by intervention methods; and

(b) how closely such a model could comply with the requirements set out in the Orders for Science in the National Curriculum.

The conclusions may be summarised as:

(i) The first case study established the value of work experience which was curriculum-based on 'techno-science'.

(ii) The second case study suggested that:
a) based solely on the information from the questionnaire, the differences in teaching and learning styles measured before and following intervention do not yield a consistent pattern;

b) other information, such as the statistical evidence from the analysis of trends in the number of students opting to study science at A-Level and the achievements of the test group in GCSE examinations and AT1 (experimental and investigative science) skills, pointed to the success of the predictions based on the hypothesis.

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CONTENTS

Introduction and aims

This intervention research work introduced specific learning experience for pupils in order to study the relationship of school science and applications in industrial technology. A major emphasis is the close relationship between science and technology and detailed attention is given to the defence of a 'techno-science' paradigm (based on an integrated approach to science and technology and defined in chapter 4 of this work). In the framework of this paradigm, the work focussed on the learning process and the skills required by teachers to implement effectively the investigatory approach advocated in Attainment Target 1 (AT1) of the Orders for the National Curriculum for Science (1989), particularly the 'extended investigations' described at levels 8 to 10 of AT1 in that Order.

It should be noted at the outset that this work was based on the 1989 Orders for Science in the National Curriculum as these were in force at the time of commencing the research. During the life of the research programme, revised Orders for Science appeared in 1991 and 1994 and the implications of the changes for this work were analysed. Consequently some aspects of the intervention programme had to be modified. For example, some of the original East Midlands Science Teachers Action Research (EMSTAR) group which was established in April 1991, felt unable to participate in the development and implementation of extended investigations and the follow-up evaluation when the requirement for extended investigations was removed in the 1994 Orders. This reduced the number of potential case studies. However, the change also enhanced the value of this work, as it investigated a teaching and learning approach which appeared only briefly as part of the Science National Curriculum.

The aims of the work were :

1. To review trends in practical work in science classes in British secondary schools over the past 150 years, and to pay particular attention to the relationship between school science and technology, as a foundation for adopting a 'techno-science' educational paradigm.

2. To establish, on the basis of the above review, and aspects of educational psychology, the place of team problem-solving investigative practical work in secondary school science.

3. To devise a working model of team problem-solving investigative practical work, set in the 'techno-science' context of real industrial problems, as the basis for intervention research in schools.

4. To design and evaluate a research instrument for investigating practical work for use in the school science laboratory learning environment.

5. To carry out field tests which:
(i) investigate whether 'techno-science' provides a successful approach for involving pupils in educational activities which span the science-technology continuum, and extend to cross-curricular activities such as work experience schemes.
(ii) use the research instrument, together with other evidence, to evaluate the effect of the working model on the learning achievements of pupils at Key Stage 4.

In this thesis, chapter 1 provides a brief overview of the historical development of practical work in science in secondary schools, which, together with the critique of investigative practical work in school science in chapters 2 and 3, form a theoretical basis for two major aspects of the secondary school curriculum relevant to the hypothesis in this thesis: Firstly a 'techno-science' paradigm is described and defended in chapter 4. Secondly, problem-solving both as an intelligent activity and as a process within science education is defined. This establishes a theoretical foundation for the hypothesis which forms chapter 5 of this work, and a three-dimensional working model of extended problem-solving 'techno-science' practical investigations was developed from the work of other researchers active in this field (described in chapter 6). It was hypothesised that teaching which respects and utilises the techno-science paradigm will produce more effective learning both in school science and, in a wider curricular context, extra-mural activities such as work experience, which relate classroom science to industrial technology.

To enable field testing of the hypothesis, it was firstly necessary to devise a research instrument to measure changes in teaching and learning skills which might result from techno-science investigations. Chapter 7 deals with the instrument and research method. Chapters 8 and 9 describe how the hypothesis was tested through intervention research in two case studies, using a mixture of interview and questionnaire techniques. Chapter 10 reflects upon the statistical evidence and procedures in this work and describes some conclusions and extensions.

Chapter 1 Historical Review: 150 years of secondary school scientific practical work.

This chapter provides a brief overview of the historical development of practical work in science in British secondary schools to establish that science and technology should not be treated as separate disciplines but form a 'techno-science' continuum. This forms a foundation for the study of problem solving in science education and the fuller treatment of 'techno-science' given in chapter 4.

The 1989 Orders for Science in the National Curriculum brought the opportunity to develop and evaluate extended practical investigations (defined in chapter 2 of this work). These were required for attainment of levels 9 and 10 and allowed bright pupils to undertake small-scale scientific projects, lasting several weeks and often incorporating problem-solving technological skills. However, they were omitted from the 1991 Orders, though implicit in the complexity of the work required for levels 9 and 10. The Draft Proposals published in May 1994 stated that, in the context of attainment target 1:
"The higher level descriptions remove the present demand for extended pieces of work."

It is a central contention of this thesis that extended problem-solving investigations as described in the 1989 Orders should be available to all pupils in secondary schools and retained as a requirement for pupils of high ability in science. This contention is in contradistinction from the Orders for Science (1994) and is therefore defended in the first three chapters of this thesis on historical, psychological, educational, scientific, vocational and ideological grounds.

Nineteenth-Century Science Teaching

Before 1840 there is little evidence (1) of science as we know it today being taught either in schools or in the universities (2). Secondary education at the time was based on the classics and science was only rarely regarded as a valuable addition to the curriculum. In primary schools the teaching of science began to get under way in the 1840s under the influence of remarkable men such as Richard Dawes and Henry Moseley and by the mid nineteenth century, science teaching was well established in some schools, with laboratories and apparatus being provided from government grants.

Thanks to the intervention of men such as these, school science was related to the science of everyday things, the promotion of logical thinking and the use of language (3) However, progress wilted under the constraints of the 1862 Revised Code which brought the introduction of a system of 'payment by results', by which school grants were calculated on the basis of the pupils' examination performance in reading, writing and arithmetic. Although this system was modified about ten years later to take some account of science, the Devonshire Commissioners found a far from healthy situation in their report of 1872 on training colleges and elementary schools. The report, reflecting the views of T. H. Huxley who was to exert considerable influence on biology teaching, stressed the importance of training the young to use their hands, eyes and senses and recommended that this should be done for the youngest pupils through what were called 'object lessons' in science (4).

While elementary school science languished, science in the public schools gradually gained a foothold in the curriculum. The Schools Inquiry Commission of 1868 was sharply critical of the lack of science in many schools and provided an interesting early statement of what might be achieved through a practically oriented science course:

> "True teaching of science consists not merely of imparting facts of science, but in habituating the pupil to observe for himself, to reason for himself on what he observes, and to check the conclusion at which he arrives by further observation and experiment" (5).

By 1870 some form of science had appeared on the timetables of many public and grammar schools, but it was taught in the same manner as the contemporary classics pedagogy: book learning. Fortunately, a few individuals were far-sighted enough to appreciate the value of experimental work; Rugby and Queenwood College were among the first schools to build laboratories and to emphasise the importance of practical work in science teaching (6). Enthusiasm for practical work may stem in part from the highly popular publicising work of famous scientists of the time, particularly Davy and Faraday at the Royal Institution (7) In general, the lecture demonstration was the preferred mode of instruction, being used for illustration and verification.

The Influence of Armstrong

Before the turn of the century, another distinguished scientist, who is often regarded as the father of school science, was to exert great influence on teaching. This was H E Armstrong (8) who had received a liberal scientific

education under Edward Frankland at the Royal College of Chemistry in London, before eventually becoming a Professor of Chemistry. Early in his career he lectured in chemistry at St Bartholomew's Hospital, where he was astonished at the inability of his medical students to interpret simple experimental results and at their general lack of a critical stance. He suspected the root cause lay in school science teaching, and went on to lead what can only be described as a crusade for the improvement of the teaching of science in schools, through what he called the heuristic or 'finding out' method. Armstrong believed that the pupils should be placed in the position of an original investigator and should try to discover answers to problems for themselves; pupils should perform many of the experiments and thereby discover scientific knowledge for themselves. In that way science would 'come alive' to them and they would be helped to grasp the principles better. The use of eyes and hands - scientific method - cannot be taught by means of blackboard and chalk or even by experimental lectures and demonstrations alone; individual eyes and hands must be practised actually and persistently from the very earliest period in the school career (9).

On account of his high reputation as an academic chemist, Armstrong was able to use the British Association as an outlet for his powerful arguments. At the British Association meeting in 1899 he described his ideal science course in six stages.

1 Lessons on common familiar objects.
(Involves observation, description, classification)
2 Exercises in measurement.
(Numerical measurements in a physical setting, e.g. volume, density)
3 The effect of heat on various elements and compounds.
(Observation and recording)
4 The problem stage.
5 Quantitative determination of the composition of compounds.
6 Introducing theory, particularly the molecular and atomic theories.

Stage 4 is the seed of genuine pupil investigation. It exemplifies the heuristic approach and is the most radical, with problems such as determining what happens when iron rusts; separating the active from the inactive constituents of air; determining what happens when sulphur burns. The emphasis was on observation and hypothesising - skills which were echoed nearly 100 years later in the 1989 and 1991 Orders for the National

Curriculum for science, where for example we find on page 3 of the 1989 Orders in a description of Attainment target 1,

> "The activities should encourage the ability to:
> i. plan, hypothesise and predict
> ii. design and carry out investigations..."

With Armstrong's influential advocacy, the heuristic approach rapidly gained supporters, and prompted the following observation in Nature (1901):

> "A revolution which gathers strength every day. The system of science education by didactic methods still exists in places, but only because the machinery for carrying on the work on more rational principles has not been obtained. "
> The journal went on to provide its own interpretation of the approach in 1904:
> "Two things are essential for Professor Armstrong's plan, first, that the pupils should perform experiments with their own hands, and second, that these experiments should not be the mere confirmation of something previously learned on authority, but the means of elucidating something previously unknown, or of elucidating something previously uncertain. "

During the early years of the twentieth century there was a rapid growth of schools taking up Armstrong's heuristic suggestions. Laboratories were appropriately equipped and teachers trained in the 'Armstrong method'. The guidelines from the Board of Education stressed the importance of individual work, along with complete and accurate recording of all observations, exact expression and correct inference. The emphasis throughout was on method of enquiry rather than subject matter and represented a swing of the pedagogical pendulum from didactic teacher-led methods to the opposite extreme.

By the end of the century, Armstrong's heuristic method had exerted considerable influence. Both the Association of Headmasters and the Oxford and Cambridge Local Examination authorities had adopted his proposals. Only a few teachers, however, actually embraced his method in their teaching; heurism had become accepted in principle, but not wholly in practice. It is noteworthy that another sixty years had to pass before a further attempt - this time on a massive scale - was made by the Nuffield Foundation to promote a form of discovery learning in science teaching.

Predictably, such a radical idea, calling for an entirely new approach by teachers, encountered opposition. By the end of the First World War, there had been some major criticisms of the heuristic method: the emphasis on laboratory exercises led to a bias towards measurement while neglecting other aspects of the pursuit of knowledge; stressing training in experimental method reduced the teaching of scientific principles and of science as a humanising influence. The first of these criticisms arose because teachers were giving their own emphases to Armstrong's course, perhaps finding the earlier stages (e.g. exercises in measurement) much easier to handle with large classes than the later, heuristic elements (e.g. the problem stage). It is worth noting here that a similar problem arose in the 1960's in the delivery of Nuffield science courses, particularly physics, where the freedom allowed to teachers was the greatest, and anxiety resulted in teachers reducing the open approach to an easier closed pedagogy. Deficiencies in Armstrong's view of scientific method became clear, particularly in the inadequacy of his view that careful measurement of everyday phenomena constituted scientific method. The most powerful attack was mounted in the Thomson Report of 1918 (10) which stated, after a thorough analysis of the heuristic method,

> "We are driven to the conclusion that in many schools more time is spent in laboratory work than the results obtained can justify . . . insistence on the view that experiments by the class must always be preferred to demonstration experiments leads to great waste of time and provides an inferior substitute. The time gained by some diminution in the number of experiments done . . . could be well used in establishing in the pupils' minds a more real connection between their experiments and the general principles of science or the related facts of everyday life."

In effect it was restricting what was taught in science lessons to those topics which could be studied practically by students in the laboratory. Discussion of the relative merits of individual experiments and demonstrations was not new but reached new heights at this time, fuelled partly by the critique of heuristic approaches and partly by the arguments about saving teaching and learning time produced by proponents of general science and science for all.

The twentieth century

a) 1900-1960

Heuristic teaching is far from easy to practise, and it is not surprising, that it became less popular in the twentieth century. A rather formal and specialist style of science teaching became fashionable that was, for the most part, detached from the applications of science to be found in everyday life. Then the First World War brought about significant changes in thinking about science. On the one hand there was concern about the neglect of science, while on the other, the view that science courses in schools should be broadened and humanised was gaining ground. In 1916, the Association of Public School Science Masters published two important pamphlets: *The Aims of Science Teaching in General Education* and *Science for All.* While the members of the Association doubtless had primarily in mind boys in the Public Schools in which they worked, it is noteworthy that the notion of 'science for all' which is today widely accepted goes back to the early years of the century. It is perhaps not surprising that the advocacy of providing the opportunity for more pupils to do practical science ran aground on the reefs of lack of resources. As early as the 1920s, in response to situations in schools where there was insufficient apparatus for every group of pupils to perform the same experiment at the same time, many teachers had developed a worksheet system, called the 'card' system, where different groups were carrying out different experiments following instructions from a printed card - a circus approach.

Between the Thomson report of 1918 and the important Science Masters' Association/Association of Women Science Teachers (S.M.A./A.W.S.T.) of 1957 and 1961, comments on practical work in official reports are generally restricted to debate about the relative merits of demonstrations and individual practical work. The nettle of providing adequate resources was left ungrasped. However, Part 2 of *The Teaching of General Science* listed, for the first time, pupil abilities which should be tested in examinations, with a section on practical skills (11). This included

(a) the development of manual skills and dexterity,

(b) the ability to do neat, accurate work, and

(c) the ability to apply science to solve practical problems.

This type of simple classification of skills was not developed again until the 'objectives movement' of the 1960s. A further section of the report discussed the development of scientific modes of thought, specifically the ability:

(a) to explain the principles from facts and to support principles with facts,
(b) to distinguish between fact and hypothesis, and
(c) to plan experiments and draw conclusions.
This provided a more rounded view of a scientific approach than that put forward by Armstrong.

The Spens Report of 1938 (12) discussed experimental work in detail and criticised the waste of time in much of the then current laboratory practice. Against the background of the strengthening general science movement there re-appeared a strong commitment to more demonstration work, thus:

> "A larger variety of experimental work, covering more ground and carried out more accurately and skilfully, will provide more data over a wider variety of topics than is possible where the only, or the main, experimental work is done by the pupils. By a greater use of good demonstration we believe that science teachers will more commonly stimulate wonder and imagination."

Once again the emphasis was back on factual knowledge rather than the process of how this knowledge was gained by painstaking effort by experimental scientists.

During the late 1950s many interested parties expressed concern about the state of science education in schools. It was at this stage that the two strands of factual knowledge vis-a-vis scientific method were most clearly formulated which were to stay, largely separate, for the next 25 years. A watershed for future curriculum development had been reached. At this time secondary education in the United Kingdom was still sharply divided between a majority in secondary modern schools and a selected minority in grammar and independent schools. The two strands can be matched to the two systems. For example, in 1953, and 1957, the S.M.A. published a report, in two parts, on Secondary Modern Science Teaching (13). This pointed to a more child-centred and relevant approach. The students' practical work was more investigative and open-ended. Subsequently, in 1960, Her Majesty's Inspectors of Schools published *Science in Secondary Schools,* (14) which advocated 'science for all students throughout their secondary schooling' and gave perceptive criticism and guidance concerning practical work. The report contained critical descriptions of laboratory work where:

> "The end is known, to the master at least if not the pupil, and the *modus operandi* has been carefully thought out and tested by the former so as to produce a certain recognised result. There is nothing, as a rule, to correspond to the clear formulation of a question by the

pupil himself; this is provided for him and no value is placed on curiosity. Nor is there any necessity to construct a plan of investigation, to design and make *ad hoc* experimental devices or to modify them in the light of experience. Nor, again, if the answer comes out 'right' , is there much inducement to consider the results, to estimate their validity or to discuss their further improvements. Finally, there is missing the ultimate satisfaction of having really found something out."

The report advocated that pupils should carry out real personal investigations as part of their laboratory work. Not that these should replace entirely the demonstrations or practical exercises but that

". . . original investigations could be introduced into the practical work rather more frequently than at present."

In 1961 the Association for Science Education published a series of policy statements, under the heading of Science and Education, and put forward the view that

"all pupils should follow a balanced core of science subjects up to the end of the fifth-form year to ensure that those leaving school were properly educated or truly cultured and therefore able to participate fully in the life of their time'.

These general principles were developed into a framework of content and practice in three separate booklets for biology, chemistry and physics, leading to a course which was comprehensive, coherent and modern. The topics to be covered were laid down in some detail, with suggestions for experimental work. This practical work was to be linked closely to the theory, to illustrate or to derive it. Although some of the experiments were described as of a 'research or project nature', it was clear that such were perceived in a very convergent and theoretical way. For example, experiments to discover 'the laws of reflection of light' or 'whether the extension of a spring is proportional to the load', were classed as being of a research or project nature. And so, around 1960, close to the beginning of the involvement of the Nuffield Foundation in the funding of curriculum development projects in science, two competing approaches to practical work in science teaching were clearly articulated by the A.S.E. and H.M.I.

No outline of this period would be complete without a mention of the science experienced by those pupils who did not gain entrance to grammar schools. There was a limited provision for these children before 1944 in senior schools. The 1944 Education Act established the tripartite system of secondary

education, but most children went to secondary modern schools. By the end of the 1950s, these schools had begun to acquire a distinctive way of teaching science which emphasised the need to make science interesting and relevant to ordinary children. The teacher training colleges which served these schools were sufficiently independent from the universities to be able to help in the process by stressing the need to make science teaching more 'child-centred' and less academic than it was in the grammar schools. It is unfortunate that since secondary modern science teaching lacked the status of its grammar school counterpart, secondary modern teachers were not often encouraged to publish accounts of their experience of teaching science. Consequently, much of the experience and wisdom of the finest science teachers in the senior and secondary modern schools died with them. Fortunately, however, some of it did find its way into a report of the Secondary Modern Schools Sub-Committee of the Science Masters' Association that sat under the chairmanship of H F Boulind. This report, *Secondary Modern Science Teaching,* (15) provided a great deal of useful guidance and paved the way for the publication in 1960 of an influential document by the Ministry of Education, *Science in Secondary Schools* (16) and, some five years later, one of the earliest publications of the Schools Council, *Science for the Young School Leaver* (17)

b) 1960-1990: the Curriculum Development Era

The Nuffield Secondary Science Project

1961 saw the launch of the largest co-operative venture of its kind ever seen in Britain. About thirty projects, resulting in the publication of hundreds of books, were pump-prime funded by the Nuffield Foundation, and later funded by the Schools Council and other agencies. Waring (18) has explored some of the educational, political, social, and historical factors that led to the establishment of the Nuffield Science Teaching Project in 1961-62. This development in Britain was not due, as is sometimes assumed, to a single factor such as the launching of the Russian Sputnik in 1957(19). The reasons go back much further in time, and are far more complex. Significant influences (20) include the patient work of small groups of teachers in the Science Masters' Association and the Association of Women Science Teachers that culminated in the important policy statements (21) of 1957 and 1961, the large-scale curriculum development movement that got under way in North America (22) during the 1950's, anxieties about the lack of scientific manpower, and the climate of opinion around 1960 which was caught up to some extent in the space-race and was favourable to the propagation of

science. It was clear from the outset that the large-scale development of new science curricula would require very substantial funding, and in the notable absence of financial support from the government, the Nuffield Foundation provided £250,000.(23)

The initial brief

The Nuffield Foundation thus provided the impetus for the first attempt at curriculum reform on a national scale and assumed a more active role than simply providing the necessary funds. The Foundation, at the outset, gave some direction in the form of guidelines. These were of a general nature, and capable of detailed interpretation in a variety of ways. Principal among them were, that the products of each of the teams should:

(i) be a co-ordinated set of non-prescriptive materials to be of use to teachers in any way they wished.

(ii) provide some insight into scientific thought and method; and

(iii) be equally suitable for future science specialists, for those who would later specialise in other subjects, and for those who would leave school early and take up non-academic careers.

However, it was highly significant that the first projects were based in Ordinary Level specialisms (24) and thus clearly geared to grammar schools so that the final part of guideline (iii) was largely ignored (though NSS did later address this). Secondary Modern schools were considerably slower to benefit from the project and its associated funding to schools for the purchase of new apparatus.

There was agreement in all the teams that it would be desirable to:

(i) reduce the amount of, and to bring up to date, the factual side of the subjects;

(ii) develop practical work as a basis for thinking about science, and relate it with theoretical work as closely as possible; and

(iii) emphasise important principles and skills in scientific thinking.

As the Nuffield initiative had a profound effect of the development of practical work in schools, here follows an analysis, for each of the initial projects, of what has been written by the curriculum developers about practical work, and short commentaries on the responses to the use of materials in schools.

Nuffield Ordinary Biology

In this course it was stressed that experimentation and enquiry were to be emphasised ahead of 'mere factual assimilation'. One of the aims concerned with practical work was:

> "to teach the art of planning scientific investigations, the formulation of questions, and the design of experiments (particularly the use of controls). "

Class practical work was seen as either using information, techniques and concepts or working them out. It was strongly promoted as being an investigative or problem-solving activity. The writers recognised that it was important for younger students to experience a sense of achievement in their practical work, and that this requirement could well be in conflict with the presentation of a genuine experimental situation which involved a degree of uncertainty. Thus the initial bold statements about genuinely investigative approaches were soon qualified!

Demonstrations on the other hand allow the teacher control over the imparting of a piece of information, the introduction of a point for discussion, the description of a concept or technique. Without providing any, it was stated that the evidence available suggested that, for the purpose of imparting knowledge, the demonstration was as efficient as, if not better than, class work. Group practical work was encouraged, where different groups studied different aspects of the same theme, followed by a period of pooling and discussion of data. Long-term investigations lasting two, three or more weeks were suggested for biological systems. However, the revised course acknowledged that there were serious problems in maintaining this work with large numbers of students and suggested the provision of data for analysis as an alternative in some cases (once again diluting a bold intention and drawing back from a firm requirement that pupils have the opportunity to engage in at least one extended investigation).

Nuffield Advanced Biology

This course was developed end-on to the Ordinary Level course and therefore some continuity of aims might be expected. The Advanced Biology course is firmly within the framework of science as enquiry, and stresses the importance of developing skills and techniques of experimentation. Much emphasis is placed on the role of 'investigations' in the course which can either involve practical work or be based on second-hand data. The majority of the investigations 'have been carefully designed to provide reliable

results' and carry instructions for experimental procedure along with questions that provide a guide for analysing the results. Should they be more properly called practical exercises? Certainly, when considered in the light of the current interpretation of the term 'investigation' (which includes active pupil involvement in hypothesising, designing appropriate experiments to test their hypotheses, drawing inferences from their own results and using these to evaluate the hypotheses, as well as engaging in evaluating the whole investigation) these Nuffield-style 'investigations' were little more than confirmatory experiments. On the other hand, extension work was given which was much more open-ended and which relied heavily on the student's initiative. Each student was required to complete a project which was formally assessed and which would occupy approximately 30 working hours.

Commentary on the Biology courses

Dowdeswell and Kelly (25) commented that although supporting enquiry approaches and investigations, those teachers involved in both courses at the development stage recognised that there was a problem in providing open-ended investigations suitable for use in the ordinary classroom with whole classes, particularly with the pressure in the early years to obtain 'satisfactory' results from experimental work on which to build theoretical understanding.

Kelly, writing of the Advanced level course, recognised the difficulties with practical investigations:

> "The practical work in the Laboratory Guide has been carefully vetted and tested to ensure that it can be successful. Furthermore, the student is guided to some extent by lists of procedures and questions. In these respects, then, it is contrived and does not provide a student with the experience of tackling a genuine open-ended problem. A project, on the other hand, provides the opportunity by which students can individually gain this experience." (26)

Nuffield Ordinary Chemistry

The Chemistry writers clearly had the aim of encouraging pupils to be scientific about a problem and of understanding Chemistry as being a way of conducting an enquiry. They argued that the basis for this enquiry must be firmly experimental. Experimental work was to be undertaken in such a way as to awaken the spirit of investigation and each experiment would normally involve three equally important stages:

(i) planning how to tackle the problem,
(ii) carrying out the experimental work, and
(iii) discussing what deductions can or cannot be made from the results.
It was readily acknowledged that the experimental work presented to the pupils, and its outcome, would normally be well known to the teacher. The situation which was familiar to the teacher was taken as new to the pupil and the phrase 'guided investigation' was occasionally used by the organisers in descriptions of the project . The two major parts, or stages, of the course indicated a view of how science develops from concrete experience to theoretical insight:
Stage 1 (age 11-13) A time for 'doing experiments' in order to learn about a wide range of materials and some of their patterns of behaviour. Practical skills of measurement and observation were to be acquired and the beginnings of training in disciplined speculation.
Stage 2 (age 13-16) A time for attempting explanations in terms of particular models. These models were developed only when they could be used. Practical work in this stage was very different and was slanted more towards testing theoretical models or ideas.

Nuffield Advanced Chemistry

The approach to practical work in the Advanced Chemistry course was a logical continuation of the approach of Stage 2 of the Ordinary level scheme. With the emphasis being put on a strong integration between theory and practical work, the strategy was to use theoretical principles to predict the outcome of reactions, then to test these predictions experimentally. Practical work was to provide the basis of theoretical discussion and practical techniques were to be acquired, not as ends in themselves nor to satisfy examiners in practical examinations, but only as the necessity arose during some theoretical investigation. The requirements for the compulsory teacher assessment of practical work provided guidance about desirable practical abilities: to observe, to interpret observations, to plan experiments, and to manipulate.

Commentary on the Chemistry courses

Writers such as Halliwell, Tremlett and others (27) commented that the role of practical work was clearly stated in the two programmes which formed a coherent progression from investigations related to the study of materials to experiments more closely linked to theoretical development in Chemistry.

Nuffield Ordinary Level Chemistry was probably more closely associated with the resurgence of Armstrong's ideas than any of the other courses.
It was, however, significant that in none of the published materials nor in the connected writings of the team members at the time were words like 'heurism' or 'stage-managed heurism' used. The closest phrase used was 'guided investigation'. The writers were at pains to point out that they understood the limitations of student experimentation particularly with respect to the time consumed (the familiar rapier thrust against heuristic approaches from the Thomson Report onwards). There was little scope for genuinely open-ended investigations where pupils were responsible for designing experiments to address problems of their own devising. Investigations were limited to practical work designed to elucidate well-known theory.
G. Van Praagh, an advocate of learning by discovery, writing in the School Science Review on 'Experiments in school science, summarised the position:

> ". . . a guided tour with some rewarding discoveries en route, rather than an undirected exploration." (28)

Nuffield Ordinary Physics

The original Ordinary level course had remarkably little to say by way of justification of laboratory work. The major argument was presented in terms of students acquiring the feeling of doing science, of being a scientist. Students were asked to mirror the activities of the scientist in devising their own experiments, meeting difficulties as well as successes, and trying things out with a watchful eye and a critical mind. Both student experimentation and demonstrations were encouraged, with the acknowledgement that student experimentation would take a long time and that perhaps the number of such experiments should be restricted, with an associated strengthening of the role of demonstration work. The writers appear to take almost literally the Bruner dictum:

> "The schoolboy (sic) learning physics is a physicist, and it is easier for him to learn physics by behaving like a physicist than doing something else. "(29)

The revised course added very little regarding the philosophy of practical work, but there was one important commentary where the writers defended themselves against being labelled as 'heuristic' or advocating the 'discovery method'.(30) They argued that they did indeed want students to do their own experimenting, but with reasonable guidance and not under the illusion that they were doing new science. The urge for discovery and the delights of

personal success were to be encouraged without deceiving students about history. This stress on personal discovery, and the desire to develop in the students a total reliance on the validity of their own results, was reckoned to be so important that no student texts were published with the course. That, it was argued, would have undermined the basic philosophy by allowing the students to turn to the text for the 'right answer'. If the absence of a student text enabled the student to write freely, if insecurely, the form of the teachers' guides caused the teachers to respond more prescriptively. Teachers found it difficult to work from the often verbose and idiosyncratic teachers' guides, preferring to lean on the more specific guides to experiments. Consequently, some tended to follow the recipe without appreciating the rationale, producing courses which were little more than a succession of 'experiments to be done'. It is ironic that this course, which exemplified the laudable aim of giving teachers and pupils the greatest freedom was often reduced in practice to a convergent prescription.

Nuffield Advanced Physics

The experimental work was prescribed in some detail in the Teachers' Guide and Students' Guide and justified in the Teachers' Handbook. Although it was admitted that there was probably not a 'best way' of teaching the course, five particular types of practical work were suggested:

(i) Demonstrations, either as polished performances by the teacher or as foci for discussion with student involvement, were included.

(ii) For some topics a series of related experiments are provided either suggested by previous ideas, or needed to open up a new topic These can be done by different students who report back their findings to the class as a whole.

(iii) 'Individual exploratory experiments': where students were encouraged to decide for themselves what to do with some apparatus provided, not knowing what will happen.

(iv) One or two long experiments were suggested, to give students the satisfaction of completing a task of some degree of complexity and of overcoming a number of difficulties on the way.

(v) To yield experience of working as an investigative physicist, with completely open investigations to be undertaken on an individual basis. Here the students were expected to identify their own problems, invent their own (simple) experiments and deal themselves with the difficulties that arose. These investigations were seen as a fundamental part of the design of the course and aimed to help students to become better at doing physics rather

than to teach them more physics. Two weeks in each of the years were to be set aside for two individual investigations the second of which was formally assessed. The investigations were included in order to provide the student with the opportunity to experience something more of the art of enquiry than was normally possible with the main, structured experiments in the rest of the course. By enquiring, the student learned more of how to enquire and might also begin to understand the sensitive relationship between theory and experimentation. Investigations were further justified in terms of the enjoyment and involvement evident in the way in which students tackled this aspect of their work, and the responsibility which was thus given to them.

Commentary on the Physics courses

Wenham and others (31) noted that both courses brought together, or developed, a range of experimental work which was both elegant and ingenious and enabled students and teachers alike to share in practical work previously used only by the most innovative teachers. This was most welcome and refreshing to courses which had, for many, become arid and didactic. The Ordinary level course was perhaps too radical in its rather idealistic and ill-defined emphasis on a 'content-led discovery learning', an emphasis which needed perceptive teacher insight and commitment if it was to have any chance of success. The practical work was framed predominantly by the theoretical content that it was intended to illustrate or to 'discover' and, although it was suggested that some experiments were to be used to develop the investigative approach of 'being a scientist for a day', the examples given were generally convergent.

It sought to provide 'physics for the enquiring mind', and all the physics that an educated pupil should know before leaving school, but this was, perhaps with hindsight, too ambitious and academic for the needs of the majority of pupils even within the top 25% of the ability range. The lack of an assessment of practical skills in the Ordinary level Physics course caused some dilution of the intended aims of practical work. It is worth noting at this point that this role of assessment is a significant feature of the National Curriculum Orders regarding Attainment Target 1. Regular commitment to assessment can lead to clarification and reinforcement of practical work aims.

In contrast to the Ordinary Level arrangements, the Advanced Physics course provided more specific aims for practical work which were stressed in the examination process. The first part of the assessment was based on

teacher assessment of work done by the students in their second investigation. The second part, designed to test particular experimental skills and techniques, was made up of a series of eight short exercises to be done in a single 90 minute examination. These approaches emphasised again the importance of practical assessments in influencing the types of practical work being done. This was especially true of the Advanced Physics investigations, where students consistently showed themselves capable of achieving scientific investigative work of a very high standard.

Nuffield Combined Science

Nuffield Combined Science, the course which provided the overwhelmingly popular basis for the development of science courses in the 11-13 year age range, broke little new ground in its brief rationale for practical work - it effectively mirrored the approaches of the separate subject courses from which it was derived. As a consequence, different sections of the course carried the marks of the Nuffield Ordinary level materials. The familiar message was reiterated in the Teachers' Guide:

> "In order to gain as much first hand experience as possible of science as a method of enquiry, children must be attentively engaged in laboratory work. In this way children will develop an appreciation of how to formulate, test and modify hypotheses."
>
> And again teachers were urged to allow students
>
> "time to . . . design experiments and activities to test their suggestions . . ."

Nuffield Secondary Science

The Nuffield Secondary Science course was developed as a pragmatic response to the needs of 'that part of the 14-16 year old population not provided for by the first generation Nuffield courses' i.e. the Secondary Modern School pupils. Because it was not confined by adherence to Ordinary Level syllabi, it was, to some extent, free to explore new approaches.
In dealing with this part of the population, the Newsom Report was sharply critical of much practical work in science, arguing that

> 'Too much of the tradition of science teaching is of the nature of confirming foregone conclusions. It is a kind of anti-science, damaging to the lively mind, maybe, but deadly to the not so clever.' (32)

The project team was, therefore, insistent that the work presented must have significance for the students and must involve the investigation of real

problems (which are presumably meaningful and relevant vis-a-vis contrived ones). In this there are echoes of Pamphlet No. 38 (Science in Secondary Schools) (33) and the secondary modern tradition of science teaching. Idealism was, however, tempered with realism. The writers argued strongly that a greater element of investigation was crucial, while recognising that students who were not high fliers would need considerable help in posing the questions to be asked if their enquiries were to meet with adequate success. They accepted that the use of open-ended experiments will have to be carefully regulated if confusion and depression from an apparent lack of progress and achievement are to be avoided. This is an important issue with implications for the management of pupil investigations and will be discussed more fully in the section of this work devoted to problem solving. Alexander, in her evaluation of the course, found that teachers were providing a fairly high degree of support for the student through structured situations, while giving freedom within the framework. She found evidence of a move towards student participation, though not of a totally open-ended approach.(34)

The Implementation of Nuffield-sponsored Science Courses

It was one thing to produce impressive curriculum packages, but quite another to achieve classroom reality. The Nuffield development teams had been very hesitant to produce syllabuses for their courses in order to stimulate creativity, preferring instead Sample Schemes and Teachers' Guides which became the reference points for those involved in developing new public examinations. In the case of practical work there was no such hesitation. Experiments were developed, tested and then made available to teachers in recipe format. The writers suggested that, although 'true experimentation and discovery' is present in some pre-secondary schemes e.g. Nuffield Primary Science, and genuinely experimental investigation in Nuffield Advanced level schemes with projects (Biology, Physics and Physical Science), other examples are not easy to find and many of the Nuffield courses have spawned contrivances designed to produce the "right" answer nearly every time'. The student is therefore lulled into the belief that something has been discovered as a result of turning a switch to start a device which cannot normally fail!

Of the impact of the Nuffield courses, Her Majesty's Inspectors of Schools had this to say in 1979:

> "The Nuffield Science Projects have had a great influence on the introduction of practical work in science courses of all kinds. The

pendulum has swung too far in some areas, however, with so much emphasis on class practical work that demonstration lessons are rare." (35)

Such comments appear to be very similar to those made by teachers and Her Majesty's Inspectors 20 years earlier, 'Plus ça change, plus c'est la meme chose'!

From Nuffield to the present

Having viewed science education trends from a broad perspective since the mid-nineteenth century, I shall now focus on those aspects which are most directly relevant to the work in this thesis and which it seeks to develop.

Long before the so-called Great Debate of 1976/77, science education was criticised for being too academic, divorced from technological and social applications and lacking investigative practical work which enabled pupils to apply their scientific knowledge to realistic problems drawn from everyday life.

Contrary to popular opinion, this issue was not raised by politicians or industrialists but by science teachers themselves. The criticism can be traced back to 1918 when the committee chaired by J.J. Thomson claimed that the traditional science course of the time was too narrow, out of touch with the many applications of science and so failed to satisfy the natural curiosity of pupils. It recommended that more attention be paid to those aspects of science that bear directly on the objects and experiences of everyday life. Once again, in 1953, a report by the Science Masters Association (36) placed a strong emphasis on the need for practical work, arousing and maintaining the interest of the pupil, and on the need to teach material that is of social relevance and pertinent to an educated citizen. The unifying principle of this report was that of *education through science*, a term that was to re-appear twenty-nine years later as the title of the 1981 policy statement (37) of the Association for Science Education (ASE). Returning to 1961, the Science Masters Association in its policy statement (38) lists among its objectives for the intermediate phase of schooling in the two or three years prior to the school leaving age that:

"school science should relate facts and principles to everyday life and experience".

The same points were raised in the Newsom Report (39) in 1963 which laid great emphasis on practical enquiry in the early years of secondary school and stressed the study of science in the context of occupation and further education. However, this early criticism was largely aimed at science teaching in secondary modern schools and not at the academic curriculum of the grammar school. The 1965 policy statement of the ASE (40) stressed the need for all pupils to study science, based on the premise that those who have no understanding of the effects of science on human life 'cannot be considered properly educated'. However, two separate science curricula existed in parallel for pupils who were placed in distinct types of school depending on the outcome of sitting the eleven-plus examination. It was the Schools Council (41) who addressed this curricular dichotomy by arguing that one should not assume one kind of science for academically gifted pupils and another for the less able. The Government Circular 10/65 issued in the same year requiring the establishment of comprehensive schools by local education authorities in England and Wales set the agenda for radical change. However there was only a gradual removal of 11+ selection and another twenty one years would pass before all pupils in state education would begin to study syllabi leading to the combined common examination at sixteen plus - the General Certificate of Secondary Education.

Nevertheless, from the mid-1960's, "comprehensivisation" was a major revolution in the organisational context within which science was taught in secondary schools. These changes in the system of education as a whole were concurrent with curriculum developments, typified by the work of the Nuffield Science Teaching Project, discussed above. For our present purpose, it is sufficient to notice that, in the Nuffield approach to science, although the objectives varied in detail from project to project, there was broad commonalty and those of the chemistry project will serve as an example. Amongst the qualities to be encouraged in Nuffield Chemistry listed in Nuffield Chemistry, *Introduction and Guide* were:

> "Skill in devising an appropriate scheme and apparatus for solving a practical problem.
>
> Ability to apply previous understanding to new situations and to show creative thought.
>
> Awareness of the place of chemistry among other school subjects and in the world at large."

The appropriate areas highlighted here are: practical problem-solving, applying knowledge creatively to new situations, particularly those related to the world at large. Pupils could not follow the new courses successfully by relying heavily on the kind of rote learning all too common in the past; they would now need to work most of the time in the laboratory and considerably more would be demanded of them by way of understanding. Furthermore they would now be expected to have some appreciation of the historical, social and applied aspects of science, as well as some insight into scientific thought and method. Similarly in the A-level projects, a contemporary view of the disciplines was put forward, and the historical, applied, social, environmental and economic aspects were not overlooked. However, although the Nuffield schemes included some interesting applications of science in technology and everyday living, they did not go very far in illustrating the social relevance of science. Consequently, in 1978 John Lewis (who had been a member of both the 0-level and A-level physics teams) wrote - after discussing the positive contribution that the Nuffield projects made to science education - in the general introduction to the trials version of the Science in Society Project:

> "But in one aspect these innovations have failed. The new programmes particularly in physics, have tended to look inwards on themselves . . . Though the programmes have shown something of how the scientist thinks, they have done little to show the relevance of that science to the world outside the laboratory . . . We have done far too little to show the importance of science and technology in the world today, especially at a stage when important decisions are made about future courses of study" (42)

The 1971 ASE Paper, Science and General Education (43), whilst acknowledging the changes in this turbulent period of changeover to comprehensive education, still found it necessary to emphasise the need to link science studies to everyday life and to applications where change had been inadequate. Also absent was a curricular model which provided an explicit method of including technological applications and social implications. This weakness was addressed in 1973, some twenty years on from the report of the Science Masters Association, and a curricular framework (44) was produced by the ASE whereby science education would have three aspects: 'science for the enquiring mind', 'science in action' and 'science for citizenship'. The same document also suggested that the ASE

would create a means for discussing in depth 'the place of technology within education in general and within science education in particular'.

So the scene was set for Prime Minister James Callaghan to deliver his speech at Ruskin College, Oxford, in October 1976. The so-called Great Debate seized the headlines and science education was high on the political agenda, at last. The Green Paper of 1977 (45) was the first outcome of the Great Debate and covered the four main topics of that debate (the curriculum, the assessment of standards, the education and training of teachers, school and working life). It placed emphasis on the relationship between schools and the world of work and the underlying assumption that wealth creation is based on the effective application of science and technology to the needs of society. In the formulation of aims of schooling, the DES included:

> "To help children to appreciate how the nation earns and maintains its standard of living and properly to esteem the essential role of industry and commerce in this process;
> to provide a basis of mathematical, scientific and technical knowledge, enabling boys and girls to learn the essential skills needed in a fast-changing world of work.

In 1979 the ASE brought out its own radical consultative document (46) which had a catalytic effect on discussion throughout science education. Some fourteen years on from the introduction of comprehensive schools, the ASE argued that the science curriculum was still firmly rooted in the academic traditions of the grammar and public schools with little evidence of any attempt to create a comprehensive school curriculum with an appropriate science provision. In the section on the curriculum, the document comments on the science curriculum development projects of the 1960's such as Science 5-13, Nuffield Junior Science and Nuffield Secondary Science:

> " A major weakness, however, of all these developments is the failure to move away from the behaviourist assumptions that characterised the previous decade".

Three science curricular models were presented, with the third representing a full integration of scientific, social and technological aims and contexts. But this model was ahead of its time as can be appreciated by comparing it with the discussion paper produced by the Royal Society (47) in the same year which concentrated on the effects of comprehensive school education on talented children and argued for the study of separate sciences to GCE 'O'

Level for these pupils with an alternative provision for those with average and below average ability.

An influential pioneer venture into the arena of integration in the late 1970's was the Schools Council Integrated Science Project (SCISP) (48). It is striking to note the close similarity of the thinking in the 1918 Thompson report with that of the stated aims of SCISP. These aims bear a relationship to those of preceding separate science subject projects but the SCISP scheme is distinguished by the breadth of its science content, its attempt to get to grips with technical and social aspects of science, and the importance given to the attitudes to be developed in pupils. SCISP was said by its writers to be the first scheme to adopt a genuine 'process' approach. Again it was stated that pupils should be able to demonstrate their degree of competence in:

(i) using patterns and making critical appraisal of available information in order (a) to solve scientific problems and (b) to make reasoned judgements; understanding the significance, including the limitations, of science in relation to technical, social and economic development;

(ii) designing and performing simple experiments, in the laboratory and elsewhere, to solve specific problems and to show perseverance in these and other learning activities.

It is noteworthy that pupils were to be encouraged to design experiments not only in the laboratory but elsewhere. This, together with the aim concerning relating science to economic development points the way to industrial problem-solving investigations with perhaps extra-mural hands-on experience using equipment at the industrial site.

SCISP also addressed the important area of attitudes to be developed in pupils and we find stated in the aims that pupils should

> "Be concerned for the application of scientific knowledge within the community."

The SCISP project made a notable contribution in the direction of broadening science education to incorporate more practical applications, industrial and economic consequences and their social effects and this was developed in the more recent Science in Society and Science in the Social Context (SISCON) (49)

Joan Solomon, arguing in favour of Science and Technology in Society (STS) for schoolchildren (50) wrote:

> "There is just one brave venture into this field which has also tried to present the social face of science; this is the SCISP (Schools Council Integrated Science Project).....

> The Schools Council, for example, has produced 'Jackdaw'-style teaching packages that cover many of these STS problem areas; the Association for Science Education has designed an O/A level syllabus entirely devoted to science in society. Only the tip of the STS iceberg is visible in the material published for examination courses.....
> In the SISCON-in-Schools project (SISCON means 'science in a social context'), we are developing a new strategy for teaching STS to the sixth form. To give the pupils a feel for the way in which science and society interact.....
> Though teaching about science and society in schools may still be in its infancy it is beginning to kick. We shall know it has come of age when *all* the public examination papers in science include questions related to the *living use* of science alongside those which test our pupils' ability to memorise facts and solve numerical problems."

It was clear on all sides that there was a climate of innovation and consultative documents from interested groups abounded between 1979 and 1981. It is worth noting the collaboration of Government departments on the matter of vocational preparation (51) and the injection of a consultative document (52) from the Manpower Services Commission followed very quickly by its agenda for action (53) which laid the foundation for the very controversial, influential and well-funded Training and Vocational Education Initiative (TVEI) of the 1980's. TVEI brought five criteria to bear on curriculum development, encompassing

(i) teaching and learning styles;
(ii) technology across the curriculum;
(iii) equal opportunities;
(iv) guidance and support;
(v) community and industry links.

This initiative will be explored in the section of this work devoted to problem solving.

In the early 1980's Science education was being pulled in opposite directions: Some, like the Royal Society argued for the retention of the highest academic standards allowing able pupils to pursue all three science disciplines to the age of 16, requiring about one third of their timetables; others like the Department of Employment and the Department for Industry looked for more relevance to the needs of working life; still others wanted stronger links with technology, science in action and science for citizenship. Clearly all

these requirements could not be met within a reasonable school timetable allocation, so the question of how much time could be devoted to science became central.

The answer came with remarkable speed in the form of DES and Welsh Office proposals in 1980 (54) that all pupils should spend between ten and twenty per cent of their time studying science. The Training and Vocational Education (T.V.E.I.) funding criteria also specified an upper limit of 20%. This immediately aroused opposition as it precluded the option for bright pupils to choose three separate sciences, and gave rise to the slogan, 'three into two won't go!'. Added into this conflict came the Finneston Report (55) which on the one hand expressed concern at the standards of mathematics and science teaching whilst on the other hand argued for the need for better school-industry links to facilitate the introduction of industrial applications of science.

Faced with this impossible situation and the fierce on-going debate, the ASE in its 1981 policy statement (56) backed away from the more radical elements of its 1979 paper on alternative models and eschewed any further attempts to take the lead in the critical area of science education in the comprehensive school. The Association failed to develop further genuine curricular alternatives. The Government paper 'The School Curriculum' (57) which represented the conclusion of the Great Debate, was no better, providing little guidance but requiring schools to write down their own aims and evaluate them, and hinting darkly that

> "It will be possible to accommodate science in the 11-16 curriculum on the required scale...only if courses can be developed which (do not make) unacceptable demands on curriculum time."

The Department also made it clear that it intended to take the lead in defining the aims for the science curriculum. Black and Ogborn (58) perceived and criticised the potentially far-reaching implications of the DES broad-based curricular proposals, but the full impact of the statements did not become clear until Kenneth Baker, the Secretary of State for Education, unveiled the 1988 "Great" Education Reform Bill. It became law the same year and gave him and his successors extensive powers over the curriculum. This was unprecedented in the history of British Education. In 1989 the National Curriculum (59) was published, duly entered the statute book and the "balanced science for all" curriculum model for science in the comprehensive schools was launched into the schools just in time for the

start of the Easter holidays, and leaving little time for planning prior to implementation the following September. It was therefore not entirely unexpected that practical problems arose in delivering the National Curriculum in science, particularly the unwieldy assessment procedures, and that a second edition emerged in 1991. This, whilst appearing to reduce the number of attainment targets from 17 to 4, achieved this by a process of amalgamation which left the load of subject contact largely intact. However, in the process of scientific investigation dealt with in Attainment Target 1 (Sc 1) with which this work is mainly concerned, there was a shift away from the requirement for 'extended investigations' at levels 9 and 10. These provided an opportunity for the most able pupils to engage in small-scale personal research, although being an exciting innovation, encountered much opposition. This was due to the unfamiliarity of teachers and examination boards with this form of school practical work, leading to concern over how such investigations could be delivered. Many science teachers were daunted by the need to address the heavy and complex demands of a rapidly implemented statutory National Curriculum, and found the experience stressful. Consequently there was considerable resistance to the idea of trying out new forms of practical work. This was the context for the extensive consultation process in 1993 managed by Sir Ron Dearing, whose report paved the way for the third edition of the Science Orders. One casualty of this stress and concern was 'extended investigations'. Predictably, these were completely removed in the Draft Order of May 1994, and the A.S.E. noted in its commentary published soon after,

> "Extended pieces of work will not be required at the higher levels which will reduce the demand on pupils, teachers and resources."

However, whilst the pressure was building for increased relevance of school science to everyday life, the growth of a whole new area of the school curriculum was gaining momentum. Technology was emerging as a separate school subject, independent from science and quickly established a strong empire and funding allocation in competition with science. This dichotomy between science and technology in schools was, and still is, an area of considerable importance in any consideration of practical work in schools, so we shall discuss it next as an issue in its own right.

Science and the growth of school technology.

In August 1988 the DES published its proposals for the National Curriculum in Science (60) and stated in paragraph 2.2 that

> "It is a continuous process by which individuals and groups develop an understanding of the physical and biological aspects of the world."

In the immediately following section on the contribution of science to the school curriculum, six ways are listed:

> "i. understanding scientific ideas,
> ii. Developing scientific methods of investigation
> iii. Relating Science to other areas of knowledge
> iv. Understanding the contribution Science makes to society
> v. Recognising the contribution science education makes to personal development
> vi. Appreciating the nature of scientific knowledge."

In terms of linking science and technology, is important to note the paragraph on the contribution of relating Science to other areas of knowledge:

> "Just as Science cannot offer an adequate explanation of our world on its own, so science education needs to relate to other areas of the school curriculum. Pupils should be encouraged to recognise and value the contribution which Science can make to other areas of learning, and the knowledge, skills and inspiration which scientists can derive from other activities."

And again in understanding the contribution Science makes to society:

> "Pupils should be encouraged to study the practical applications of Science and Technology and the ways they are changing the nature of our society and our economy. They should be helped to explore some of the moral dilemmas that scientific discoveries and technological developments can cause. Science education should encourage all pupils to appreciate their responsibilities as members of society and give them the confidence to make a positive contribution to it."

These two statements clearly encouraged cross-curricular activities which explored science and technology in a societal context.

The writers, in writing on the nature of technology, commented:

"Technology is a creative human activity which brings about change through design and the application of knowledge and resources. Technology involves drawing on human knowledge and resources in order to make things work, control things and alter the way they work."

It is perhaps unfortunate that this statement contained a faint suggestion that only technology is creative, since this adjective was not also applied to science, whereas it was mentioned explicitly in the Programme of Study in the 1991 Orders (61). This tendency to separate science from technology resulted in a list in the section on primary schools, which, while recognising that young pupils perceive science and technology as a single area, proposed five distinctively technological activities: (62)

"• practical problem-solving,
• designing and making,
• using experiences, knowledge and skills from other subject areas;
• investigation, innovation, and evaluation;
• designing and implementing a system."

Before discussing these, it should be noted that this separation continued:

"Whereas Science is concerned with the pursuit of reliable knowledge about the physical and biological world, Technology is led by human needs and involves meeting those needs or solving identifiable problems. It is concerned with optimisation, and with balancing costs and benefits in any solution."(63)

Thus, in seeking to establish that technology is more than applied science, the authors pushed separation too far. The above paragraph for example, begs the question "Does medical science not address human needs?" Using the description of science given in the document and stated above, leads to the conclusion that medical research i.e. the pursuit of medical knowledge and understanding, is science, not technology.

Returning to the list of five distinctively technological activities and taking each item in turn, the present writer would suggest that 'practical problem solving ' is not an activity which is confined to technology. For example the Statement of Attainment for level 4 of AT1 in the 1991 DES Orders for Science (64) requires pupils to:

"ask questions, suggest ideas and make predictions based on some prior knowledge , in a form which can be investigated."

In the illustrative example provided, where pupils could consider how best to keep water in a container hot, is this not just another way of solving the

'technological' problem of how to store hot liquids? Neither, secondly, is the skill of designing confined to technology since pupils are required to design their own investigations in science. The human activity of designing cannot properly be limited to artefacts, but must include processes, including therefore scientific methods of investigation. The third activity in the list is clearly intrinsic to science, as indeed is the fourth, since AT1 activities should:

> "encourage the ability to plan and carry out investigations in which the pupils:.....evaluate scientific evidence."(65).

Indeed, the final technological activity might be translated into science with equal facility as "Design and implement a systematic investigation."
The authors admitted that:

> "Children do not see the boundaries between one form of knowledge and another since they are intertwined at this stage." (66).

It seems reasonable to suggest in the light of the above discussion that the two areas are intertwined at any and all stages.
A key statement was:

> "Technology, however, is more than applied Science -it draws the knowledge it needs for solving problems from many disciplines." (67)

This drew attention to the breadth of technology as a synthetic activity going beyond applied science, but produced an amorphous 'super-subject', a portmanteau catch-all which schools have found difficult to interpret and manage.
The 1989 DES Orders for Science (68) tackled this difficulty:

> "Scientific and design & technological classroom activities may be difficult to distinguish. Indeed, some teachers have been introduced to design & technology through practical science and vice versa. There are, however, important differences in style and purpose between the two. Whereas science is enquiry-led and concerned with the pursuit of better investigative strategies and more reliable knowledge about the physical and biological world, design & technology is led by the desire to meet human needs and opportunities. Furthermore, design and technology needs to take a wide range of factors into account, optimising and balancing costs and benefits in any solution. Clearly, there are important connections between science and design & technology: science draws on design & technology in developing its instrumentation and techniques of enquiry; significant discoveries have depended on the development of particular tools, materials or techniques. Design & technology is more than applied science. Whilst

drawing on the knowledge it needs for solving problems from a wide range of disciplines, it has judgmental aspects, such as:

- deciding what is worth doing and is achievable;
- generating and appraising possible solutions;
- reconciling conflicting demands;
- making decisions on the basis of imperfect information;
- achieving outcomes within constraints of time and cost."

Woolnough and Allsop made a most useful contribution to this discussion by distinguishing between two aspects of technology: (69)

> "We see technology as having two quite distinct elements, one of relevance to science practical work, the other not. The first and central element in technology is problem-solving, the open-ended design process in which a problem is established and analysed, possible solutions considered, and the optimum solution selected, implemented and evaluated. This is defined most commonly as 'a disciplined process using scientific, material and human resources to achieve human purpose'. This is very similar to the investigative approach of a problem-solving scientist and matches very closely our approach through investigations. Some distinction has been made between technological investigations which are set in the context of some specific human need and science investigations which may be followed purely to satisfy curiosity. Technological investigations are more likely to involve making some device than are scientific investigations, which may well use standard laboratory apparatus, but this distinction is not an important one.
>
> The second element of technology relates to the application of science and the implications of technological processes and products for society. This field is vitally important for science teachers to be involved with." (70)

Before leaving the 1980's, there are three further aspects of science education which emerged strongly:

(i) Research results reported in 1985 by Driver et al (71) Osborne and Freyberg (72) showed that pupils' enthusiasm for science declined from a peak at age 11 to a low level by age 16. Also, only a small minority attained a satisfactory grasp of even the most elementary concepts by the end of their GCSE courses.

(ii) The work of the APU science monitoring group (Black 1990) (73) brought a greater emphasis to process skills and led to more complex views of the essential links between the learning of concepts and skills (which is explored more fully in the section below on the impact of psychology on science education). This in turn highlighted the importance of pupils doing their own investigations, culminating in the emergence of AT1 of the National Curriculum (1989).
(iii) There was a strong movement towards environmental science, the interface between man and his environment and the moral issues which this raised. This led some to promote the study of social, technological, environmental and personal implications of science e.g. Lewis (74), Solomon (75), Holman (76), Hunt (77). Others argued for a more human approach which would discuss scientists as persons developing their contributions in particular historical contexts and this led to AT17 which focused on the history of science. A third group criticised science teaching for failing to give explicit attention to the methods of science, and yet presenting, by implication, quite false views about them e.g. Hodson (78), Lucas (79).
These three strands combined to support a call for broader, more humanistic aspects of science to be included in the school curriculum by e.g. Matthews (80,81). The stage was set for a further decade of change. Black (82) identified four principal drives which he believed would shape science curriculum development in the 1990's:
(i) the influence of changes in research emphases in science and technology e.g. AIDS, genetic engineering, environmental concerns;
(ii) changes within education itself produced by pedagogically relevant research and by the effects of information technology;
(iii) changes in society leading to changes in societal expectations of its schools; political interest in education shows no sign of dwindling;
(iv) radical changes in pupils themselves due to influences outside the school such as the media and high divorce rate; Hamburg's review of the condition of children in the USA talked about a generation in crisis (83)

The trend towards a more humanistic approach to school science was given additional impetus in the late 1980's and early 90's by the Manpower Services Commission (funded, not by the D.E.S. by the D.T.I.) which was provided with a substantial budget to introduce a pilot Technical Vocational Education Initiative (TVEI) where a relatively small group of schools received large sums of money in a well-publicised campaign. This was followed immediately by the full national phase during which a large proportion of secondary

schools in England and Wales opted in, and where the sums were smaller but still attractive. The extension phase in the first half of the 1990's brought the scheme to a conclusion. The Initiative required that, in order to secure funding, a given school had to demonstrate that its curriculum was changed in specific directions which were evaluated against 5 criteria:

(i) Teaching and learning styles;

(ii) Technology across the curriculum;

(iii) Equal opportunities;

(iv) Guidance and support;

(v) Community and industry links.

One example of how TVEI funding together with money from other sources, was used in 1993/4 (as part of the intervention research programme in this present work) to facilitate a project to develop links between science, technology and the world of work, in given as an appendix. In 1994 the main emphasis of TVEI shifted towards post-16 education and the development of materials for the General National Vocational Qualification (GNVQ).

The present position

Finally, in early 1993, following widespread dissatisfaction amongst school science teachers with the first two Orders for implementing the National Curriculum in science (1989, 1991), the Secretary of State for Education, John Patten, invited Sir Ron Dearing to conduct a review of the National Curriculum in science. There were four key issues:

(i) The scope for slimming down the curriculum;

(ii) the future of the ten-level scale;

(iii) how to simplify testing arrangements;

(iv) how to improve the administration of the National Curriculum and the tests.

The Review began in April 1993 and Dearing produced his Interim Report in June 1993. The final Report, published in January 1994, led in to a review of all ten National Curriculum subjects, with the aim of having the review completed in time for schools to start teaching to the new curriculum from September 1995.

The Interim Report

Between April 1993 and July 1993, Dearing carried out wide consultation on the key issues. Views were invited from a sample of 1400 schools; teachers from over 500 schools were consulted at 9 regional conferences; and over

2500 other schools, organisations and individuals sent in responses. In the Interim Report, five main ways forward were outlined:
(i) Slimming down the National Curriculum by dividing each subject into an essential core and additional option material, and by reducing the number of statements of attainment;
(ii) ensuring that the essential core takes up less school time, allowing schools discretion over what to teach in the remaining time;
(iii) limiting the national tests in 1994 to the core subjects, reducing the time load and making Key Stage 2 tests a voluntary pilot;
(iv) giving assessment of pupils by teachers equal weight to standard attainment test (SAT) results in reports to parents;
(v) improving administration of the National Curriculum by making all documents shorter, clearer and producing them earlier to allow schools more time for planning.
The Government accepted the Interim Report and the Review continued.

The Final Report

The Final Report re-affirmed that the National Curriculum and assessment and testing is the key to raising standards. No further changes should be made to the National Curriculum at Key Stages 1 to 3 for 5 years. In areas relevant to the work reported in this thesis, it recommended that:
(i) Urgent action is required to reduce the compulsory content in the programmes of study and to make it less complex and prescriptive.
(ii) A closely co-ordinated review of all the statutory curriculum Orders should immediately be put in hand, guided by the need to:
- simplify and clarify the programmes of study;
- reduce the amount of taught content;
- reduce prescription to allow more scope for professional judgement;
- ensure that the Orders are written in such a way as to offer maximum information and support to teachers.

(iii) In the medium term, a GNVQ option should be developed for Key Stage 4.
(iv) The ten-level scale should be retained up to the end of Key Stage 3, but reduced in complexity.
In March 1994, the School Curriculum and Assessment Authority (SCAA) completed its review of the individual subject Orders and in May 1994 produced Draft Proposals for Science in the National Curriculum. Level descriptions replaced statements of attainment and in the case of Attainment Target 1 (Experimental and Investigative Science - the area of special interest in this present work) these, together with the programmes of study,

focused on the ways in which scientific evidence may be obtained and evaluated. In particular, the higher level descriptions removed the previous requirement for extended investigations. This latter change occurred in order that (84)

> "Pupils can therefore carry out work which, while rigorous, does not place excessive demands on time and resources."

So the Proposals abolished one of the most challenging activities for able pupils, namely that of devising extended investigations to test their own hypotheses, which provided an introduction to, and practical experience of, the skills needed by undergraduates working on projects, graduates working towards higher research degrees and all those involved professionally in experimental scientific work both in universities and in industry. Furthermore, whilst setting out with the laudable objective of removing duplication of content in science, geography and technology, there has been some movement towards increased compartmentalisation of subject disciplines; e.g. microelectronics disappeared from Physical Processes and was transferred to technology. This is an area where scientific understanding, rather than just a systems approach, is essential to provide a foundation for the study of post-16 physics e.g. 'A' Level. Similar losses in the other strands lead to the same effect and hence increased concern that the scientific knowledge base available to scientifically-able pupils in comprehensive schools is being eroded continuously and is far less substantive than was the case when such pupils could study three separate 'O' Levels in science. The effects on higher education remain to be seen.

Summary

In conclusion, it is a central contention of this work that science and technology form a continuum. Enough has been said and written over the past 150 years about bringing applications into science teaching, and more recently about bridging the gap between science and technology. There is no gap. It is a continuous body of knowledge. The movement to bring the separate sciences together and which resulted in the present balanced science structure of science in the National Curriculum was based on the recognition that there is no cognitive barrier between biology and chemistry, no gap between physics and chemistry. It has been shown in this work that it is equally valid philosophically and educationally to assert that there is no dichotomy between science and technology. It is a continuum involving method, knowledge, activities, context, application to, and concern with, the needs of society. As with the science disciplines, there are

distinctive features, particularly in the type of knowledge ('knowledge that' as opposed to 'knowledge how') and there is some difference in purpose and outcome, but these are not central issues and should not be used for separationist purposes. The investigations described later in this work illustrate how activities which exploit this continuum lead to increased understanding, greater enjoyment and so enhanced achievement. By encouraging pupils to explore activities throughout this continuum in contexts which use everyday applications of science and technology to solve human problems, positive attitudes are developed in pupils. The importance of such pupil attitudes is drawn out in the 1988 DES proposals:

> "Children's attitudes are also important for learning in Science and Technology. Attitudes affect the willingness of individuals to take part in certain activities, and the way they respond to persons, objects, or situations. There is less likelihood of progress without a willing participation in learning." (85)

One of the most useful summaries of how this continuum could and should be achieved in schools is to be found in the 1989 Non-statutory Guidance for science:

> "The nature of the experiences which pupils engage in, their records of achievement and the needs which may arise in their pursuit of technological problems, will be useful for teachers engaged in the design and delivery of science courses. The educational interaction of science and design & technology is powerful and each school will need to organise its curriculum so that the way in which design & technology interacts with science, as with other areas of the curriculum, allows both to capitalise on the support each gives the other. Teachers will need to take account of the pupils' perspective on how coherent this area of the curriculum appears. Co-ordinated planning during implementation, and common record keeping as the courses get under way and mature, are necessary parts of the process of delivering a coherent science and design & technology curriculum. "(86)

The significant phrase is 'coherent science and technology curriculum' and it must be emphasised strongly that such an integrated approach which arises naturally from the essential complementarity of these areas is, in the opinion of the present writer, the only educationally valid one. Some schools have already moved in this direction and secured the change through the formation of a faculty or department of science and technology in order to reflect and reinforce curricular patterns in decision-making structures.

This brief review of 150 years of practical science points up the importance of pupil involvement in practical scientific investigations which address problems in a wide variety of contexts but draw upon everyday technological applications in which the pupils are interested and reflect the essentially multi-disciplinary nature of practical problem-solving in the adult world of work for which we are preparing our pupils. In the next chapter we turn to an examination of approaches to practical problem-solving.

Chapter 2: Problem solving as an intelligent activity in the school curriculum

This chapter and the next comprise a brief critique of investigative practical work in school science in order to show the rationale behind the model and hypothesis in this work. Firstly, major features in the process of problem solving are discussed from the perspective of some recent theories in developmental psychology. A full discussion of the meaning of intelligence and its development in children is beyond the scope of this thesis. However, it is feasible to outline how the developmental theory on one hand and constructivism on the other, raise issues for science education and support the use of investigative practical problem solving as a teaching method. However, only comments related to the investigative practical problem solving area - the focus of this present work - will be referred to in detail.

The Geneva psychologists (Piaget, Inhelder et al.)

Piaget's work has had considerable implications for education, notably in the child-centred methods of the nursery and infant school, the mathematics curriculum in the primary school and the science curriculum at the secondary school level. In the case of the latter, Piaget's work formed the basis of much influential work as for example that of Shayer and Adey's taxonomic approach to the science curriculum (1).

It is shown below how his work was reflected in the 10-level hierarchical model recommendations of the working group on science in the National Curriculum whose early thoughts were summarised in an interim report in December 1987 and formed the basis for the Proposals of the Secretary of State for Education and Science and the Secretary of State for Wales, 1988 (2) and so underpinned the sequential statements of attainment approach in the DES Orders for science in the National Curriculum (1989,1991, 1994).

How intellectual development occurs

The purpose of child behaviour or thought, according to Piaget (3), was to enable the child to adapt to the environment in increasingly satisfactory ways. As children interact with the environment, they organise everything they know about a given topic into a "schema", and use this mental structure to interact with the outside world. A "schema" contains all the ideas, memories and information about a particular object that a child associates with that object. Using schemas is a way of organising our experience which

makes the world more simple. As children develop, so their schemas change and become more complex. This is done through the process of adaptation. According to Piaget, adaptation to the environment occurs through two complementary processes: assimilation and accommodation. Assimilation is the process of acquiring new knowledge by relating it to existing knowledge. A new object or idea is understood in terms of concepts or actions that the child already possesses. Accommodation is the process of modifying the way in which the person acts or the way he sees the world in the light of new experiences.

The twin processes of assimilation and accommodation continue throughout life as we adapt our behaviour and ideas to changing circumstances. As long as children are able to deal with all (or most) new experiences by assimilating them, they will be in a state of equilibrium. However, if the existing schemas cannot cope with new knowledge then a state of disequilibrium ensues and, to restore the balance, either existing schemas must change or new ones be made.

The Piagetian approach can be applied in the process dimension of science education through practical problem solving whereby adequate time is allocated to an investigative project to allow the pupils to engage in the process of problem solving, moving from one step to the next at their own pace. This process will often involve pupils in finding alternative approaches and new knowledge which challenges their existing perceptions and understandings i.e. accommodation occurs. It is the experience of the author of this work that, in order for this process to have a lasting effect, it should be gradual. Pupils need time to understand and work through the logical sequence of stages in the process of reaching solutions. In this respect, extended problem solving projects (which involve, *per se*, a period of several lessons or even weeks) meet the requirements for assimilation and accommodation.

In contrast to this, rushing through 'recipe-driven' experimental work in order to reach the expected answer, can at worst be an exercise perceived by the pupil as merely getting the apparatus to work. Little scientific knowledge is gained when attention is focused on the practical expedient of successful manipulation and the pupil is preoccupied with mechanical tasks rather than the underlying science.

Piaget argued that the young child thinks quite differently from the adult and views the world from a qualitatively different perspective. It follows that the teacher must make a strong effort to adapt to the child and not assume that what is appropriate for adult learning is necessarily right for the child. At the heart of this child-centred approach to education lies the idea of active learning: from the Piagetian standpoint, children learn from actions rather than from passive observations; for example, telling a child about the properties of materials is less effective than creating an environment in which the child is free to explore, touch, manipulate and experiment. The teacher should recognise that children need to construct knowledge for themselves (see section on constructivism, below) through active involvement in their own learning.

How can the teacher promote active learning on the part of the pupil? First, it should be the child rather than the teacher who initiates the activity. This does not mean that the children are free to do anything they want, but rather that the teacher sets tasks which are finely adjusted to the needs of their pupils and which, as a result, are intrinsically motivating to the young learners. It follows that the prime consideration when selecting teaching materials for a group of children is the readiness (i.e. intellectual development) and interests of pupils rather than the demands of the subject. Secondly, the teacher is concerned with the learning process rather than end-product. For example, the Orders for Science in the National Curriculum (1991) requires that pupils should carry out scientific investigations in which they ask questions, make predictions based on some prior knowledge, suggest causal links, formulate a strategy, use and analyse their results to explain relationships between variables and so on. From these varied experiences, children construct for themselves a knowledge base and understanding . The teacher's role is to create the conditions in which this learning may best take place, since one aim of science education is to encourage children to ask questions, try out experiments and speculate, rather than accept information unthinkingly. From this it follows that the teacher should be interested in the reasoning behind the answer a child gives to a question rather than in the correct answer alone. Conversely, mistaken ideas and conclusions should not be disregarded but treated as responses that can give the teacher insights into the child's thinking processes at one time. In the processes associated with problem solving, which are developed more fully below, there is an initial phase in which creative thinking predominates e.g. asking questions, brainstorming,

hypothesising, strategising, so that the teacher's role is that of encourager, adviser and consultant. Practical problem solving, when properly understood, thus presents abundant opportunities for pupil-centred active learning.

According to the Piagetian approach, knowledge is not something to be transmitted from an expert teacher to an inexpert pupil. It is the child who should set the pace; the teacher's part in the educational process is to create situations which challenge the child to ask questions, to form hypotheses and to discover new concepts. The teacher is the guide in the child's process of discovery, and the curriculum is adapted to each child's individual needs and intellectual level. This influence was evident in the Nuffield Science materials which were based on the principle that children begin with practical and experimental work before moving on to abstract deductive reasoning (see for example the quotation under the heading Nuffield Biology in chapter 1 above).

The teacher therefore provides the conditions which are appropriate for the transition from concrete operational thinking to the stage of formal operations. Shayer and Adey (1981) explored how science teaching techniques in secondary schools and syllabuses could be analysed in terms of the logical abilities required to fulfil them, and how they could be adjusted according to the age and expected abilities of the children. Ideally, much of this learning should be individualised in view of the wide range of activities and interest which appear in any class of children.

However, Piaget also recognised the social value of interaction as an important factor in cognitive growth. Through interaction with peers, the child is also enabled to move out of an egocentric viewpoint. This occurs through co-operation with others, arguments and discussions. By listening to other children's opinions, having one's own view challenged and experiencing through others' reactions the illogicality of certain concepts, children learn about perspectives other than their own. This provides additional support for team-based practical problem solving and is dealt with more fully in chapter 4 of this work which deals with the curricular model used in field tests.

The theory of general developmental stages in thinking has been refined, and a view of development in particular concept domains has been discussed by, for example Carey (4):
"I am not arguing that there are not domain-general changes in the developing child's conceptual system...Rather, I am arguing that much of the evidence that has been taken to support such changes actually reflects domain-specific structural reorganisations..."

The suggestion was that pupils perform differently on tasks in different contexts. Applying this idea to science education, it is the experience of the author of this thesis that problems involving levels of conceptual difficulty considered to be well beyond the grasp of pupils of a particular age, can be tackled successfully provided the level of motivation of the pupils is sufficiently high and the subject matter is presented in contexts where relevance of the problems is clearly demonstrated (see refs. 8-12). The issue here is an important one, central to the hypothesis of this thesis, namely, whether teaching style and the manner in which learning tasks are presented can influence the rate at which pupils move between stages. For example, should the teacher wait for the learner to mature to formal thinking before presenting activities and ideas requiring formal reasoning? The Cognitive Acceleration in Science Education (CASE) project (5) is an example of published materials aimed at developing the general reasoning skills of pupils in science contexts. The authors acknowledge that the cognitive level of pupils is a limiting factor in what pupils achieve, but they claim that the development of formal reasoning can be accelerated by appropriate teaching.

Bruner

The relevant aspects of Bruner's approach to child development (6) and their implications for practical problem solving may be summarised as:
• influenced by Piaget and agreed that children are born with a basic cognitive structure which matures over time. Children, he said, are intrinsically motivated to explore their environment and adapt to it by means of interaction with it. This supports the investigative problem solving approach to learning since exploration is a central activity.

• Bruner's approach differed from Piaget's as it did not explain cognitive development in terms of stages, but proposed that children develop 3 main

ways of internally representing the environment to themselves on their way to acquiring the mature thought processes of the adult. These 3 modes were: "enactive", "iconic" and "symbolic".

• Modes developed in a fixed order throughout childhood; the adult retained and used all three throughout life, not 'passing through' the earlier modes, and although adult thinking employs mainly the symbolic mode, we employ enactive and iconic thinking also when the need arises.

• Greater emphasis than Piaget on the part played by experience. He stressed that cognitive growth is significantly influenced by such variables as culture, family and education. In fact, Bruner believed that the level of intellectual development in a particular area is the extent to which the child has been given practice or experience, and that any concept, however complex, can be communicated to a child, if presented in a way that the child can initially comprehend, and developed in a manner which can be assimilated.

Implications of Bruner's theory for 'techno-science' practical investigations

1. Bruner believed that, because symbolic thought depends on language, teachers should encourage children to describe problems and events by talking and writing about their experiences in order to encourage symbolic rather than iconic representation. In the model for extended investigation in this thesis, challenging techno-scientific problems are posed to teams of pupils. The desire to solve the problem and the need for co-operation raise the level of discussion. By further requiring that solutions to problems be presented orally and in written formats, linguistic skills are developed.

2. Bruner suggested that children can be taught complex ideas and concepts as long as they are presented in a way the child can understand. For example, he has demonstrated that children of 8 years of age can be taught to appreciate the significance of the equation $(x + 1)^2 = x^2 + 2x + 1$ by using square and rectangular blocks of wood. It is also the experience of the author of this thesis that material normally taught at Advanced Level can be assimilated by 15-year olds in the context of problem solving where it arises naturally as a tool in the process of reaching a solution (7). A successful pilot scheme has been described in various articles by the author of this thesis

(8), (9), (10), (11), (12) and reported by BBC regional news and in a video film made by the author and others with a D.T.I. grant.

3. Of particular importance to this thesis is Bruner's assertion that children pass through a series of stages, but move gradually from using predominantly the enactive mode to using the iconic mode and then predominantly the symbolic mode. This is significant in the context of problem solving, since all three modes are present to different degrees. The implication from this is that practical problem solving, which involves a broad range of activities, from simple practical tasks to more complex modelling and evaluation of theoretical concepts in the light of experimental evidence, provides access to achievement by the whole spectrum of pupil abilities in a particular age group.

Hierarchical theories of intelligence

(i) Vernon (13) suggested a hierarchical model of intelligence. In this approach we have a general intelligence at the top, divided into two major groups of abilities (verbal-educational, practical-mechanical) then into several minor group abilities under each of these, and finally into specific abilities corresponding to unique tasks.

(ii) Fluid versus crystallised intelligence:

Cattell (14) suggested in 1963 that the general intelligence (g) factor has 2 components: fluid intelligence and crystallised intelligence.
Fluid intelligence is the power of reasoning and using information: it includes the ability to perceive relationships, deal with unfamiliar problems and gain new types of knowledge. It is called fluid intelligence because it can take any shape. Crystallised intelligence consists of acquired skills and knowledge and the application of the knowledge to specific areas.
Cattell argues that fluid intelligence is genetically determined while crystallised intelligence is acquired from education and experience. He also maintains that fluid intelligence reaches its peak before age 20 and then either remains constant or declines. Crystallised intelligence, on the other hand, continues to increase as long as a person remains active.

Despite the appeal of Cattell's ideas, in practice it is not always easy to distinguish between the two components. We ordinarily rely on a combination of the two, though we may rely on one more than the other. This may be illustrated by relating Cattell's theory to the subject of this

present work: problem solving would appear to lie, according to Cattell's approach, within the domain of fluid intelligence where unfamiliar problems are involved, whereas problems which can be solved purely by applying existing knowledge fall into the crystallised intelligence domain. However, in practice, a realistic scientific problem which relates scientific knowledge to some technological application in for example an industrial context, would in the opinion of the author of this work, be a mixture of both domains.

This may be illustrated by drawing on an example from the suite of problem-solving projects developed by this author in collaboration with staff from the U.K.A.E.A. in the period 1983-6 . One extended investigation involved finding a method of handling liquid highly contaminated with toxic and radioactive waste. The theoretical equations governing fluid flow were beyond the scope of the G.C.S.E. syllabus being followed by the 15-year old pupils working on the problem. So they had to acquire and assimilate this new knowledge for themselves (fluid intelligence). The pupils then had to reason their way through the unfamiliar problem (fluid intelligence). They collected measurements using their existing skills and processed the data by applying skills they had learned in Mathematics lessons (crystallised intelligence). The presentation of their results and proposed solutions to the problem used existing language skills (crystallised intelligence). This pilot scheme was recorded on video film (available from the author of this thesis) and helped to formulate the hypothesis of this thesis.

The Information-Processing Approach (Cognitive Theories)
Sternberg's Triarchic Theory:

A brief outline of this theory will be helpful prior to discussing how it supports practical problem solving.

The information-processing approach sees intelligence as the steps or processes people go through when solving problems: one person may be more intelligent than another because he moves through the same steps more quickly or efficiently or he is more familiar with the necessary problem solving steps.

Whereas Spearman (1904, 1927) and Cattell concentrated on the number of abilities that constitute intelligence, Sternberg was interested in a different question: what is the nature of the mental abilities that constitute intelligence? When people do something considered to be intelligent, what are they doing? Sternberg's theory was called a triarchic theory because he

suggested that intelligence is governed by 3 types of process which he calls: metacomponents, performance components and knowledge-acquisition components.

(i) Metacomponents are the mental abilities used in planning an approach to a problem: selecting appropriate strategies and formulae and changing performance in the light of knowledge of results.
(ii) Performance components are the mental abilities we actually use in solving a problem or completing a task. These are the abilities which IQ tests measure. Performance components include encoding information, combining and comparing pieces of information and generating a solution.
(iii) Knowledge acquisition components are mental abilities we use in gaining new knowledge. These include encoding information, combining pieces of information and comparing new information with what is already known.

Relationship of the theory to problem solving:

Sternberg conducted many experiments to determine what components were required for solving various problems. In doing so, he focused attention on the processes people go through when exercising their intelligence . His tripartite approach was reflected in the three strands in the science National Curriculum (1991) AT1 (Scientific Investigation) as shown below:

AT 1 strand	Strand description	Sternberg process
1	ask questions, predict and produce hypotheses	metacomponents
2	observe, measure and manipulate variables	performance components
3	interpret results, evaluate evidence and theoretical models	knowledge acquisition (e.g. in the comparing of patterns in measurements with known theories)

However, the metacomponent feedback loop (where performance informs improved procedure) more properly belongs to the tasks in the second strand, so the match is substantial but incomplete. We now turn to the second major school of thought in the psychology of learning - constructivism.

Constructivist psychology and its relation to problem solving: children create their own maps and theories of the world

Writers such as Brook (15), Driver (16,17), Osborne and Freyberg (18) have discussed ways in which children construct new knowledge and understanding by building on their present ideas.

In simple terms, the building blocks of cognitive thinking in science, for example energy, cause-and-effect relations, cells, heat, force, pressure, chemical change, burning, growth etc. surround the infant explorer. Incapable as children might be, according to Piagetian theory, to cope with the high level demands a proper understanding and use of these ideas requires, they cannot avoid hearing the words and experiencing the effects that they are meant to describe or explain. They read, watch television, listen to or overhear older children, parents and teachers talking. Driven by the urge to make sense of their environment, children engage their minds very actively in this process, make their own connections between experiences and the words other people are teaching them to use, and they create their own networks of relationships and patterns of thinking.

According to constructivism, children are not passive absorbers, but active constructors: this seems to be how the brain itself works. Gregory (19), describes the idea of 'kinetic intelligence' whereby children do not wait passively until they reach the developmental cognitive stage appropriate to the nature of the information and experiences confronting them. Instead they get on with it as best they can, constructing an internally consistent system that allows them to make progress. They develop an *operational* understanding of what is going on - 'When I do this, it does that . . . ', and they may not feel the need to explain why it does this. If some 'interfering adult', usually a teacher, asks for an explanation, they will make an attempt. They may have thought about it already but, if they have not, being quite imaginative, they may make it up on the spot. If told that their explanations are wrong, that for example, 'volts' do not actually 'go through' the circuit, or that 'amps' do not get used up in the bulb, they will agree but then forget, because such corrections are not necessary to their operational handling of

electricity in everyday life. As they get older they may develop a more serious interest in physics and start getting things 'right' - that is to say, their 'construct system' becomes capable of explaining a wider variety of experience - or they may not. However, more commonly, they may instead develop two systems of explanation - one for themselves to be used in solving personal real-time problems, the other to be used for doing artificial problems and 'satisfying the examiners'.

This finding supports the model of practical problem solving proposed in this work whereby pupils are challenged by a problem not only to apply their existing knowledge, but also seek new knowledge, through realising that they have inadequate knowledge to solve the problem. In this way they build their own new understanding, driven by the motivation to develop their own solution to the problem. The new ideas are not imposed artificially, but arise naturally in response to a perceived need to know. By allowing adequate time (often difficult within timetable and curricular constraints) for the pupils to develop an understanding of their new knowledge and apply it to the problem facing them, they integrate it into their 'construct system'.

This assertion was tested by the author of this work in a simple yet dramatic way. The Engineering Link Scheme described in refs. 8-12 was introduced to pupils in year 10 for the first time in 1984. Two years previously 16+ Physics had been introduced in the school. Consequently, to investigate the effect of introducing extended practical problem solving, it was necessary to research records of the grades achieved by pupils studying physics since 1982. To summarise the findings, before introducing the new methodology approximately 10 pupils achieved grade A in physics. This was in marked contrast to the cohort containing pupils who had worked on the project, where 22 grade A's were achieved. The staff , the syllabus, conditions in the school, the average ability level of the year group were all similar. The only major difference was the introduction of the project. Clearly the 27 pupils who had worked on the project (and who gained 18 grade A's and 9 grade B's - the best marks gained by a physics class in the history of the school) had learned physics more effectively through practical problem solving set in a real-world context than was achieved through teacher-led theory lessons and the usual short verification style recipe-driven practical experiments.

Further confirmation of the applicability of Gregory's ideas to science education came from research arising from the work of the Assessment of Performance Unit (APU) which suggested that a large majority of youngsters at age 15 (20) adopt the second of these alternatives, holding firmly to the ideas they formed at a much earlier age. Research by Gott (21) produced the sobering finding that even for those students studying the subject, four years of physics teaching is not enough to eradicate some incorrect ideas about very basic topics in electricity, with only about one-third correctly predicting the brightness of bulbs in a series circuit (Gott, 1985, p. 26 et seq.).

Examples of research in the UK into these 'alternative frameworks' that students use to make sense of experience are the Children's Learning in Science Project, based at the University of Leeds, where , in the section on "A constructivist approach to curriculum development", they comment:

> "Science knowledge cannot be transferred from teacher to learner, but must be individually constructed. The curriculum cannot be viewed as 'that which is to be taught', but rather as a set of experiences which enable children to make sense of scientific ideal..."

This provides support for the extended problem solving model developed in this present work, whereby pupils solve problems for themselves, with the teacher acting in the supportive role of adviser and consultant. The process may be represented in a simple form as shown in the diagram on the following page.

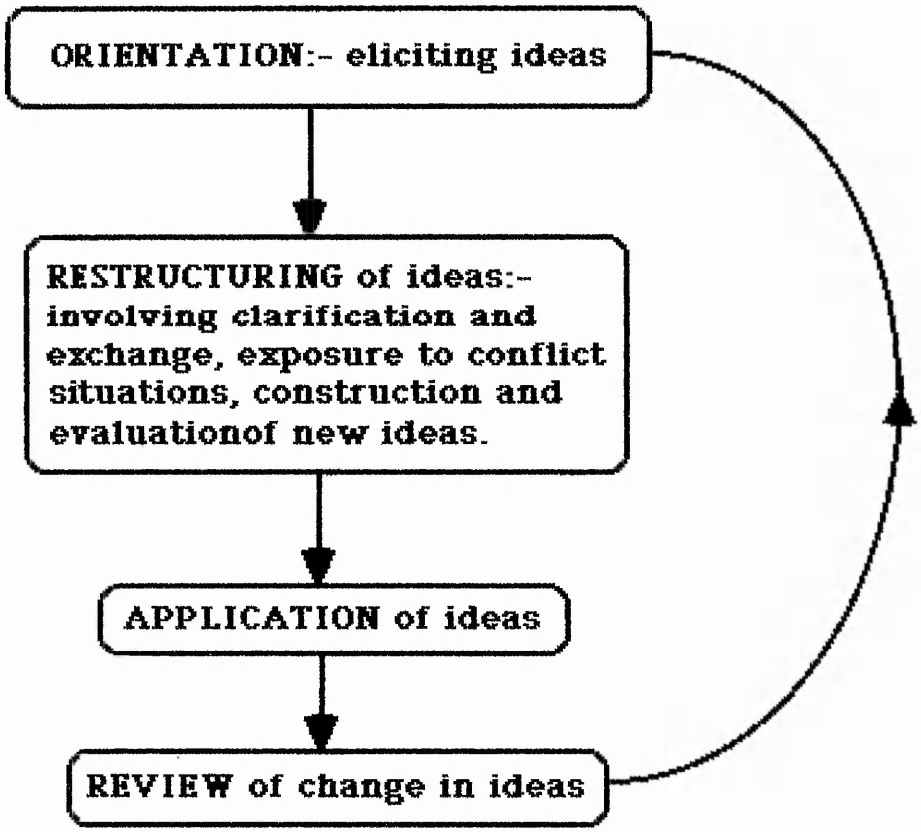


Fig. 1

Further information is provided in Rosalind Driver's book *The Pupil as Scientist?* (1983) Much of the research was done on youngsters' understanding of physics concepts, but a report of the proceedings of an SSCR conference by Bell *et al.*, 1984 (22) noted that confused or downright incorrect ideas about 'animals', 'insects', 'adaptation', 'burning', 'dissolving' were remarkably prevalent and persistent.

Commenting on the implications of constructivism for science education, Dobson wrote (23) :

> "(a) Students will only accept 'correct' ideas if they help them to make more sense of what they know;
> (b) the students themselves decide whether or not it does make more sense;
> (c) students are as strongly influenced by the 'climate of opinion' in their peer group as they are by laboratory experiments or by teachers' explanations, if not more so;"

It should be noted that Dobson's comments are borne out by the experience of the author of this thesis and reported findings on the higher level of achievement in public examinations which results from extended problem-solving practical projects. For example, point (a) above is reflected in the acceptance of new knowledge which the pupils found for themselves in order to understand the nature of the real-world problems and make sense of their experimental results. His points (b) and (c) were supported by the behaviour of the pupils on the project as they worked in teams and constantly discussed the problem, the implications of results, what further knowledge was required and so on. Thus there was extensive role of language in the process of problem solving. This is a key issue which will be dealt with more fully below, and the process can be observed on the video of the project made in 1986.

Writing on Learning Science, Asoko, Leach and Scott commented:

> "There are also areas where the science view seems entirely contrary to pupils' existing ideas and considerable effort will be required to develop a different model and to evaluate its usefulness." (24).

This reinforces the value of the use of extended problem-solving projects which provide the necessary time to allow pupils to make sense of strange new ideas through reflection and peer discussion and so internalise it into existing 'constructs'.

It is at this stage that a consideration of the role of language in science education is relevant and necessary. Pupils require time to adjust to new ideas and discuss them with their peers. In 1985 the Bullock Report (25) stated:

"When we consider the working day in a secondary school, the neglect of pupil talk as a valuable means of learning stands out sharply. To bring about a change will take time and persistence."

Dobson (26) remarked that,

"The value of students talking purposefully is difficult to assess, but the expected advantages include: opportunities to try out new ideas in a non-threatening situation; talking through and internalising new concepts; sharing new ideas..."

The above two quotations and other works on language and learning e.g. Edwards and Mercer (27) and Barnes, Britton and Torbe (28), provide evidence that task-centred pupil discussion should be an integral activity in

science education. This supports team problem solving where there may not be a single correct answer, where also the context may be unfamiliar e.g. industrial, so that it is not immediately obvious to pupils what knowledge and skills are applicable. Through discussion, pupils explore possible ways to develop solutions and their ideas are exposed to their peers and refined.

However, Asoko et al. are doubtful (29) :

> "The contexts within which work is set can cause confusion for learners. One can try to raise the relevance of a subject by relating it to, for example, industry, pupils' interests and hobbies...Many such settings are highly complex and require a balance between scientific thinking and, for example, economic or social considerations, so pupils are faced with the additional problem of recognising when and how to apply their science knowledge."

On the other hand, it is the experience of the writer of this thesis that the increased learning difficulties due to complex context are offset and indeed outweighed by the increased motivation to learn arising from the greater perceived relevance and importance accorded to science when it is seen in social and technological contexts. The key requirement in achieving success is allowing pupils sufficient time to recognise the scientific knowledge which is applicable, and discuss with others so that new approaches are constructed. Through this process, skills are transferred and pupils learn how to use their knowledge more generally, instead of within specific familiar contexts. Extended investigations which involve team problem solving would therefore seem to satisfy this requirement.

The case for using real-world contexts may be taken further by considering Ausubel's dictum:

> "Ascertain what the learner already knows and teach accordingly."

This dictum lies at the heart of constructivism. When planning lessons, the teacher needs to ascertain the existing ideas and understandings which pupils have and what changes, if any, must pupils make in their thinking if they are to integrate the new ideas into their present mental structures.

This raises the problem of language. Science provides pupils with a new way of looking at the world, but is the same world which they experience every

day, and is often described using the same words. Asoko et al. have commented:

> "Difficulties can arise, or be compounded, if the differences between the everyday and the scientific use of language are not recognised." (30)

It is the common experience of teachers that pupils will learn the scientific meanings and explanations in order to please the teacher or pass exams, but do not accept their superiority, with the result that they soon revert to their original constructs. Asoko et al. comment on this dilemma:

> "Should we be aiming to replace our pupils' existing ideas with the science point of view? Many would argue that it is neither desirable nor possible. Perhaps a more realistic aim is to help our pupils to...appreciate the contexts in which it is appropriate to use either scientific or other forms of thinking." (31)

Now it is at this precise point of difficulty, where pupils need to be persuaded to relinquish simpler familiar everyday constructs, and accept the validity and then superiority of new constructs, that extended problem solving investigations have considerable merit. They challenge pupils to use their existing knowledge to solve real problems and so assist them to realise for themselves the need to develop new ways of thinking. Some of these ways are now discussed below. Although it is beyond the scope of this work to investigate the impact of investigative problem solving on the development of specific types of thought such as creativity and lateral thinking, the link may be glimpsed in the following brief discussion.

Creativity

The creative thinker is one who generates a problem solution that is both new and appropriate. There is a tendency when describing creative thought to emphasize the 'sudden illumination' in finding a solution to a problem, but almost all well-documented cases of creative thought, both in science and in the arts, reveal a period of intensive preparation in which information is assembled, ideas tried out, solutions attempted and failures discarded. Illumination without preparation is a fictional concept.

Convergent thinking and divergent thinking:

Guilford (32) states that creativity demands divergent rather than convergent thinking. In convergent thinking, thought is limited to present

facts as the problem solver tries to narrow the scope to find the best solution. In divergent thinking the problem solver proceeds in many directions in parallel and combines elements in novel ways to find a solution and doesn't get stuck in one 'mental set'. Brainstorming is a popular term for divergent thinking when carried out by a group.

Factors in Creativity:

Creative people show flexibility, fluency and originality. Getzels and Jackson (1962) found that creative schoolchildren tend to express rather than inhibit their feeling and are playful and independent. Studies show that creative people tend to be independent and nonconformist but independence and nonconformity do not necessarily make a person creative.

Intelligence, creativity and the process of problem solving:

To bring together the above brief discussion on creativity and its development through the process of practical problem-solving, it is sufficient at this stage to note that they sometimes go hand in hand. For example, in order to solve unfamiliar problems, pupils working on the sorts of problems included in the project described in refs. 8-12 certainly had to adopt a flexible approach, being willing to discard an unfruitful line of enquiry even if was one to which a given member of the team felt ownership (due to the time and effort spent by that person). In scientific problem solving, which is discussed more fully below, an initial divergent phase is usually followed by a more convergent phase where possible approaches, hypotheses, strategies and data patterns are evaluated. Hence, the early stages of problem solving would seem to be a valuable means of developing creative thinking skills.

Problem-solving across the curriculum.

The concept of 'techno-science' (developed in the next chapter) is part of a wider issue, namely cross-curricular linkage. In Britain we tend to treat the various aspects of thinking within the framework of the traditional academic subjects, whereby the teaching of thinking is constrained within subject disciplines, on the grounds that much of the thinking we do is domain-specific. However, the teaching of thinking isn't an add-on subject but is an integral part of the teaching and learning of all subjects. Leading proponents of this view include Edward de Bono and those like Perkins and Solomon who defend it in terms of knowledge transfer.

In "Teaching for Transfer" Perkins and Solomon (1988) say that "Students often fail to apply knowledge and skills learned in one context to other situations', but that 'with well-designed instruction, we can increase the likelihood that they will'.

Much knowledge that is learned is 'inert' or 'passive'. This knowledge shows up in response to direct probes, but does not transfer to new situations. We must constantly teach for transfer - for example by

(a) teaching "metacognitively" i.e. encouraging learners to think about what they are doing, to identify the interpretative and reasoning processes which they are using to "manage" or take control over their own thinking and learning processes;

(b) constantly pointing to other applications, in related fields to which a specific approach or method may be applicable;

(c) trying to teach for transfer right across the curriculum, cutting across subject boundaries.

These ideas support techno-science practical problem solving.

SUMMARY

Before examining the application of problem solving to science education, it is useful to sum up the main implications of the work of psychologists for problem-solving as an educational activity:

(i) From the Piagetians, the lesson to be learned has been well developed by Shayer and Adey and has two strands:

- firstly that we need to be aware of the cognitive demands a course is making of students;
- secondly we plan the teaching strategy accordingly.

Commenting on Piaget's work in "How is science taught and learnt?", Dobson wrote (33):

" (a) There is no such thing as an average youngster. Young people not only develop at different rates but a given individual is also, infuriatingly perhaps, likely to develop in different cognitive directions at different rates. Some students may be thinking quite formally in, say, biology or mathematics, but are stubbornly concrete in physics.

(b) Our perception (or guess) of the youngster's stage of development could be wrong.

(c) An individual's performance is variable."

This is supported largely by Bruner's modes of thinking and the importance of linking learning to pupil experience is emphasised. Cattell's idea of crystallised intelligence also supports the need for pupils to experience science first hand.

(ii) The work done on creativity, convergent and divergent thinking has led to a better understanding of problem solving and Sternberg's Triarchic Theory has been shown by the author of this work to provide useful insight into the ways pupils may learn the process of science described in attainment target Sc1 of the National Curriculum. This advice is reinforced by the second main map-makers of learning, the personal construct school.

(iii) Constructivism has emphasised the need to start from where the child is; to consider everyday situations where science is applied and where words and explanations may well differ from those in science. Taken together with Piaget's work, we conclude that, when pupils are presented with new knowledge, the resulting assimilation and accommodation require adequate time and opportunity for discussion both with teachers and with other pupils.

Inferences for science teaching

The inferences we might make from all this about teaching style in the context of practical work in science are quite radical, (as important as what knowledge should reasonably be taught to students - a theme which was explored in depth by Shayer and Adey).

(i) There is no dichotomy between children's procedural competence in carrying out practical work and their learning of subject content. Asoko et al. have commented (34):

> "Pupils bring to their practical work, as to any other aspect of their science learning, ideas and expectations. Children's procedural competence will be influenced by their conceptual understanding, their views about the nature of the activity they are involved in and the context in which the exercise is set"

(ii) It follows that teaching styles which emphasise relevance, demonstrating the importance of science to human needs, will affect pupil perceptions and their resulting learning and competence. This assertion is

central to the present work. Further discussions and support for this view may be found in for example 'Practical work in science' by Woolnough and Allsop (35) and 'Skills and processes in science education: A critical analysis' by Wellington. (36)

(iii) This indeed, is the principal construct of the work described in this thesis, namely that a radically new teaching style is required to secure the effective pupil learning style which is associated with investigative techno-science practical problem solving set in real-world contexts. Despite the risk of pupil perplexities arising from over-complexity caused by teachers seeking to produce realistic problems, the vitally important ingredient in ensuring success, in the experience of this author, is to ensure that pupils have access to all the knowledge necessary to solve the problems. As Karl Marx wrote as long ago as 1859,

> "Mankind always sets itself only such problems as it can solve; since, looking at the matter more closely, it will always be found that the task itself arises only when the material conditions for its solution already exist or are at least in the process of formation." (37)

The next stage is to define techno-science and apply problem solving to this concept in a school context and so derive the model used by the present author. This is done in chapter 3.

Chapter 3
Problem solving in science education

The third aim of this work was to devise a working model of team problem-solving investigations as a basis for intervention research in schools. Such investigations would be set in the context of industrial technology, but used in school science lessons. In other words, they would be 'techno-science' investigations. This aim is reflected in the following two chapters. In this chapter, the meaning of problem-solving is explored, together with its purposes. The concept of 'techno-science' is defended. Finally, a three-dimensional model of techno-science problem-solving is developed. In chapter 4 a possible 'techno-science paradigm' is proposed on the basis of a comparison of the 1990 Orders for Technology and the 1991 Orders for Science. This paradigm is the framework for the main hypothesis of this work, described in chapter 5.

To review the discussion up to this point: developments in cognitive psychology since 1950 have produced the result that intelligence is not now seen as an inborn and unchanging characteristic. It is viewed as a base line to be extended by the individual concerned, by for example the structuring of experience, the development of schemata and the formation of concepts. There is a connection between language acquisition and learning achievement, as described for example, by Bruner's symbolic mode; the social context of learning can motivate individuals to achieve their potential. This was recognised by the Secondary Examinations Council in 1986 (1):

> "The General Criteria require that all syllabi should be designed to help candidates to understand the relationship of the subject to other areas of study, and its relevance to candidates' own lives. Awareness of economic, political, social and environmental factors relevant to the subject are to be encouraged whenever appropriate.
>
> The National Criteria for science underline this principle by stating that 'at least 15 per cent of the total marks are to be allocated to assessment(s) relating to technological applications and social, economic and environmental issues' (National Criteria for science, section 5). Among these matters technological applications must receive the greatest emphasis."

Also, the National Curriculum Council in the Science Non-Statutory Guidance (1993) stated:

> "If the context in which science is taught is chosen carefully, pupils can come to appreciate the relevance of the subject to everyday life. This adds interest and motivation and will lead to a deeper understanding of the importance of science in the quality of life for citizens." (2)

SISCON, Salter's Science and SATIS are *inter alia* excellent examples of projects which address the importance of context. Attitudes and motivation are recognised as of great importance. Paraphrasing Burbules and Linn (1991), the sterile character of much science teaching reinforces the lack of relevance students see for science, and leads to a lack of personal motivation and purpose in learning; this squanders one of the primary intrinsic motivations in getting students excited about science, namely peer group interaction. This interaction is one of the key activities in group practical problem solving and it is to this topic that we now turn our attention.

Problem solving is by no means a novel science teaching strategy, and many teachers in the 1990's claim to have been using it for years. However, in the 1980's it became something of a vogue term. Impetus to the trend was given by, for example, the ASE in 1981(3) ; the Cockcroft Report of 1982 (4) on mathematics, highlighted problem solving as the dominant learning strategy, and is noted for its relevance to the treatment of mathematics in the context of science education with an important principle that topics should only be included in syllabi if they can be developed so that pupils can apply the ideas in a way they can understand; the Secondary Science Curriculum Review (SSCR) in its 1983 proposals (5) suggested that there should be adequate opportunities for all students to

> "...develop the ability to design and carry out experiments, evaluate evidence and solve problems...use their knowledge of science to design and develop solutions to technological problems, to test and evaluate those solutions and to cost such exercises";

the DES document *Science 5-16: A Statement of Policy* (6) referred frequently to problem solving in different contexts. However, problem solving is a term which occurs widely across the curriculum. For example, the demise of craft-based school subjects and the rise of Design and Technology was accompanied by the claim of specialists in the new field that problem solving was the underlying rationale of their practice. This is explored more fully below. But it is not just confined to the Maths/Science/D&T field. For example health education and moral education,

if they are to achieve the curricular objectives of educating people to be autonomous and able to choose, would offer opportunities for problem solving as a significant part of the experiences that learners encounter. So problem solving may be viewed as universal in that all areas of the curriculum may use it, but nevertheless it does not necessarily involve identical activities in each curricular area.

In order to meet the second and third aims of this work, a description of problem solving was required, and this is discussed under six headings:

1. What are the types of problem that teachers are discussing and is there a taxonomy of problems?
2. What is problem solving?
3. Why do problem solving in school science?
4. What are the purposes of problem solving in science education?
5. What are the problem-solving activities in which children should be involved or the experiences they should encounter in school classrooms/laboratories that are feasible for teachers to organise?
6. Is there a 'techno-science' continuum and hence also a problem solving continuum?

1. What are the types of problem teachers which are available to schools and is there a convenient, comprehensible taxonomy of problems?

Various types of problems have been identified e.g. by Munson (7):

(i) 'Open-ended'

Open-ended problems are those which have a variety of acceptable solutions or no clearly defined solution other than an acceptable compromise or an interim solution. In the extreme such problems could be insoluble. Open-ended does not, of course, mean unstructured or undisciplined. At each stage there should be a very clear sense of direction and even perhaps a very strong expectation of a particular result. It is the willingness in pupils to be objective, to appraise and evaluate and to change direction if necessary that is the important quality to be taught.

This type of problem may well arise in a social or economic context where the variables involved are numerous and not clearly defined or controllable and their interrelationships are complex. Problems falling into this category could include, on a global scale, the economic decisions facing the world's oil

producers, or the problem of siting a nuclear power station, introducing a new market concept such as the pollution-free car. In a science context many of the problems associated with the science/technology and society interface could fall into this category. However, open-ended problems that can reasonably be tackled by pupils in a classroom within the constraints of time and resources, might need to be a narrow form of open-endedness to ensure that pupils have the confidence to tackle such problems and achieve a reasonable degree of success.

(ii) 'Egg race'

Such problems (defined objective and timescale with teams allowed to select method and apparatus) have a clearly defined objective but the means of achieving this objective can take a variety of forms. The value of such exercises derives from the opportunity they give for the participants to cooperate as a team and to explore the range of possible pathways to a solution. They are generally not intended to provide a learning medium for a specific area of the science curriculum but will obviously involve the application of a wide range of scientific concepts. They are usually good fun but really nothing more than puzzles. They almost invariably have no purpose beyond that of puzzling or of pitting one's wits against others. These aspects are not to be despised but nevertheless they are not real problems, not problems genuinely arising out of some sort of explicit need. The need might be an intellectual need to explain a phenomenon or a more practical one, maybe to design an artefact, a more efficient management technique or procedure and so on.

(iii) 'Curriculum-dedicated'

These problems are designed to complement the teaching of a particular area of the science curriculum. They usually involve the concepts and skills which are being communicated and involve the student in an interactive exercise with both peers and teacher. Used as such they offer a powerful teaching strategy. For example as a part of learning about electrical resistance and Ohm's Law, pupils may be set the problem of finding out how the resistance of a light bulb changes with temperature. At a higher level, the same context could present a problem of designing and making a simple electric balance using their knowledge of how resistance depends on length and cross-sectional area (this problem was used successfully with 15-year old pupils by the author of this work, as part of the suite of practical problem-solving projects developed for the engineering link scheme) (8). Pupils are set problems which reinforce their understanding of the topics currently being taught.

(iv) 'Closed'

Such problems have a very clearly defined solution and there is usually only one way of achieving it. Many examples of such problems are to be found in conventional physics textbooks and a significant number of examination papers! Science teachers have traditionally made extensive use of problems that could thus be defined as closed.

Do types of problems form a continuum?

The above definitions would suggest that there may be a continuum of types of problem: open-ended—egg race—curriculum dedicated—closed. In practice teachers have found that the needs of pupils, their ages and abilities, the time constraints, the context of the problem, the confidence of the pupils and their teachers, the availability of apparatus, resource inputs from agencies outside the school and so on, combine to shape the problem solving approach. Even the same problem can be tackled in a variety of styles by different pupils in the same class with, for example prompt sheets for the less able and extension tasks for the brighter pupils. In the discussion of the purposes of problem solving in section 4 below, a 3-dimensional framework is described which applies and extends the linear notion of a continuum of problem types.

2. What is problem solving?

When problem solving is being considered in the context of school science, teachers carry the responsibility for structuring appropriate learning tasks, and therefore should be able to justify them and account for them in terms of the problems' educational purposes. It is therefore important to provide a framework for problem solving so that teachers can talk to each other about their practice in terms of its purpose rather than a 'catch-all' word, which problem solving is becoming. Some of the key attempts to capture the essence of problem solving are:

(i) Writing in the 1986 edition of the ASE Science Teachers' Handbook, Bob Fairbrother (9) in a section on processes in science, describes problem solving, experimentation and decision making as including:

> "predicting, inferring, formulating hypotheses, interpreting, modelling, evaluating, assessing, classifying, and managing time."

(ii) The Assessment of Performance Unit has tackled the task of assessing the problem-solving process, especially in the context of experimental work

(10). To do this it was first necessary to define the process. Their process progresses sequentially through a number of stages:

Ia generation of the problem and a genuine perception of its meaning;
Ib reformulation into a form open to investigation;
II detailed planning of the experimental work;
III carrying out the experiment;
IV recording the results in an appropriate form;
V interpreting the results and drawing conclusions; and
VI evaluation.

The initial stages of problem solving —generation perception and reformulation —are important. Students should be actively engaged in them and ideally they should pose the problems themselves: that is to say they should tackle their own problems. Certainly the problems set should appear to be relevant to them - real problems which they feel a need to solve.

The last stage is a crucial one. The investigator must decide whether the conclusion is a satisfactory one, whether 'a good solution' to the problem has been achieved. By that we mean a solution which satisfies the investigator. If a good solution has not been found then it will be necessary to return to an earlier stage of the investigation and go through all or part of the process again. It might be decided for example that the problem must be reformulated; that the experiment must be redesigned or that it should be carried out in a different way. So the process is an iterative one and should continue until a satisfactory outcome is reached. This can best can be described diagrammatically as shown in Figure 1 on the next page. The source is APU Science in schools. Age 13:Report No.2 (1984).

In order to defend a 'techno-science' paradigm in which problem solving is, *a priori*, a central component, it is ncessary to establish a clear connection between problem solving and scientific process.
Johnsey et al. make an important contribution to the discussion by describing diagrammatically how scientific process and the problem-solving process interact (11). For brevity, they use simplified models as shown in Figure 2.

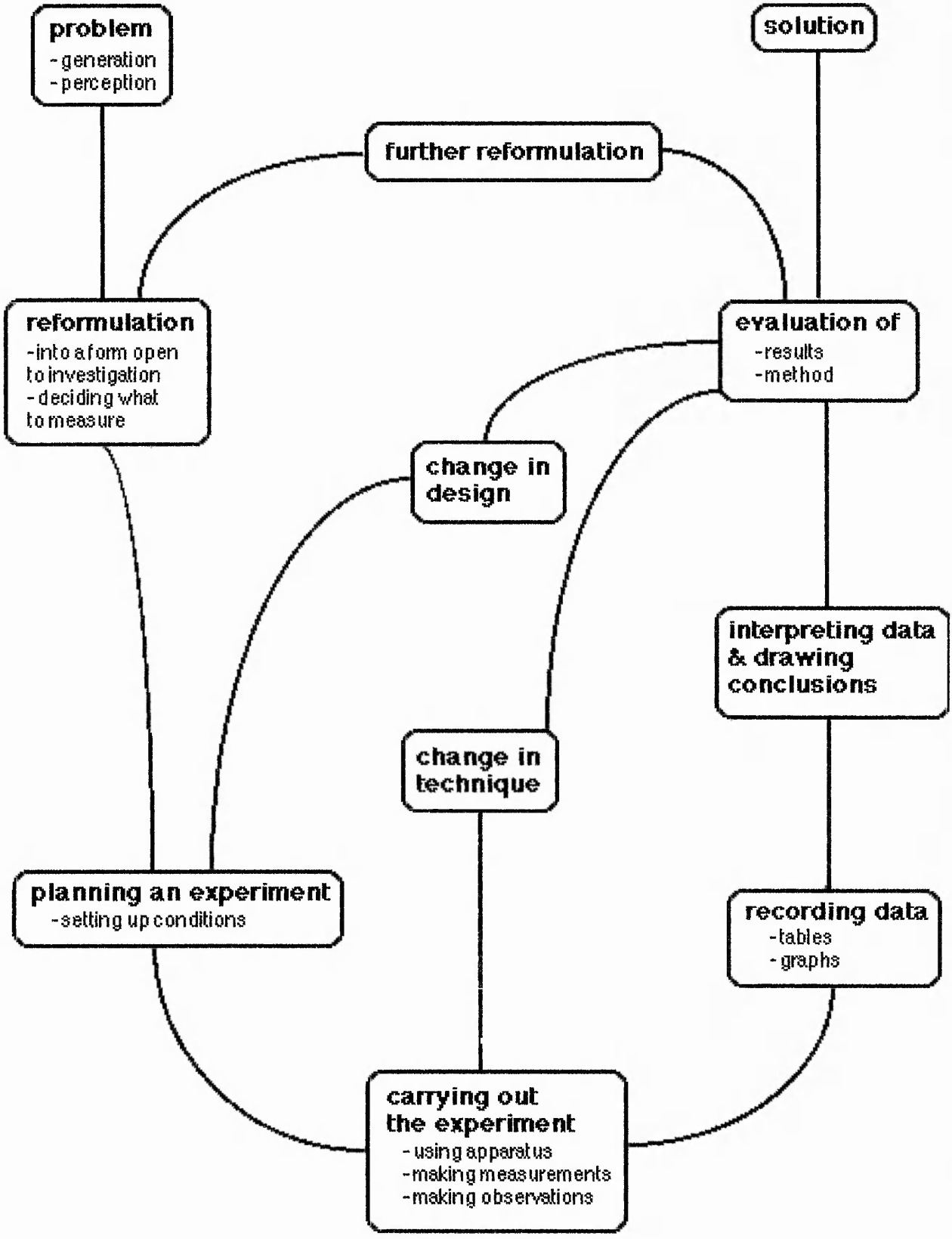
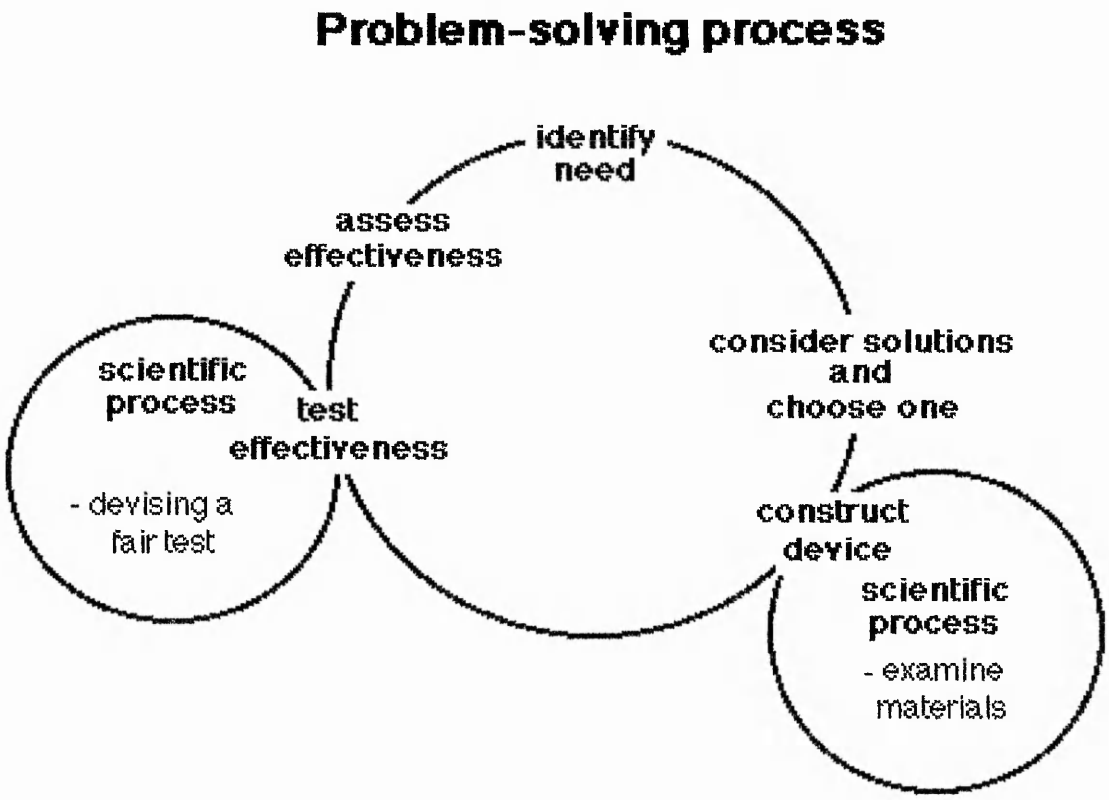


Figure 1 The APU definition of problem solving



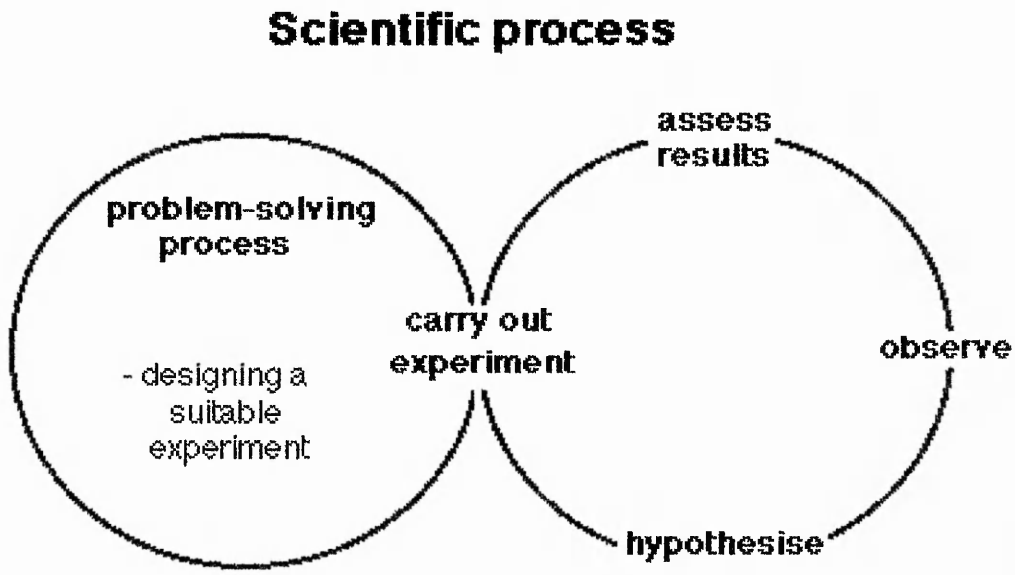


Figure 2 The interaction of problem-solving and scientific processes

Problem solving need not be a lonely business. Teamwork is often very important in the efficient resolution of a problem. We ought therefore to encourage young people to work together in groups — discussing, co-operating, criticising, sharing, encouraging, evaluating. The checklist given the in NCC's non-statutory guidance (1989) for the selection of learning experiences in science includes:

> " Will the experience offer opportunities to work co-operatively and to communicate scientific ideas to others?"(12)

This sort of approach provides a far less threatening and therefore potentially more creative environment than the more traditional teacher-centred situation. This is not to suggest of course that individual and/or teacher-directed work can never have a part to play in problem solving. In summary, there is no single type of problem solving, nor a simple definition, but a spectrum of problem-solving processes.

3. Why do problem solving in school science?

Nott (13) suggests four main strands to the reasons for doing problem solving:
educational, scientific, vocational and ideological. The following section draws upon his views.

A. The educational

These arguments advocate problem solving as a more effective method of learning. The belief in its efficacy is based on assumptions about learning (and problem solving). For example, Nott suggests it is assumed that, when problem solving:

- children will be active (learning is better through doing);
- they will be able to participate in choosing/selecting/formulating problems (learning should take account of the children's interests);
- the problems are relevant in that they relate to children's knowledge and experiences (learning should start with the familiar before it moves to the unfamiliar);
- problem solving is intrinsically at least as enjoyable as other learning strategies (the quality of learning is directly related to the children's enjoyment);
- and by encountering problems children can be challenged to find things out, learn skills or processes or question their own beliefs about the world (strong motivation promotes better learning).

It is perhaps not surprising therefore, to find in the Non Statutory Guidance for Science produced by both the National Curriculum Council and the Curriculum Council for Wales (and based on those first put forward by the National Curriculum Science Working Group, that, amongst the six reasons why pupils should have an experience of science there is the statement:

> 'to develop the necessary skills to be able to carry out scientific investigations and solve scientific problems'. (14)

In summary, it is advocated that, if children are actively involved in solving relevant techno-science problems that they have participated in formulating, then they will be highly motivated. Furthermore, they will enjoy the experience and so they will learn more efficiently whatever it is we want them to learn compared to learning with other teaching methods. The exploration of evidence *a propos* this contention is the central purpose of this work .

B. The scientific

These reasons state that problem solving is viewed as an important process that scientists engage in and therefore if children are to understand science and attain a scientific perspective and rationality they must have experience of problem solving. So the case being made is closely linked to the view that science education must start from consideration of the processes of science rather than the content of science.

The development of scientific theories and concepts can be viewed as problem solving. For example, the problems encountered with calendars and the motion of the planets stimulated Copernicus into developing a heliocentric planetary system which led to the work of Tycho, Kepler and Galileo and reached its apotheosis in the work of Newton. Problem solving in this context is creative.

Newton's synthesis of celestial and terrestrial mechanics is a most powerful tool, and problem solving can take place within its framework. The discovery of Neptune in the solar system was made possible by the application of Newtonian mechanics to explain the perturbations in the orbit of Uranus. No new concepts or skills were developed but Newtonian mechanics was endorsed with another verification. Problem solving in this context is analytic. A more contemporary example is the problem solving involved in

putting a spacecraft into orbit. The framework is again Newtonian mechanics and the problem solving is essentially analytic.

The above examples show two very different contexts for problem solving in science. Esteemed scientists were involved in both contexts. By using problem solving and teaching through problem solving, teachers can show children how scientists have worked and how they do work. This may give teachers a chance to utilise the historical development of scientific theories in their teaching. It could certainly allow children to experience, albeit briefly and simplistically, how scientists work and therefore provide them with an introduction to good practice which will educate and train them by imitating the way that scientists work. This can be done using problem solving so that children acquire and develop concepts and processes by creating their own scientific hypotheses and by applying known scientific theories to appropriate problems. This method of working also gives the children opportunities to learn the attitudes essential for scientists such as curiosity, enthusiasm and perseverance .

C. The vocational

Here, according to Nott (15), there is support for problem solving because it is a process that people will need as adults in the work-place and so its advocates appeal to a notion of a national need for a well trained scientific and technical workforce. The training that this workforce receives should be experiential in that the students should encounter and use group skills such as co-operation, collaboration, delegation and leadership. The scientific and technical training should be structured so that science is learnt through its applications and the students should learn to apply science to most situations. These applications of science will usually be technological in that they will develop an artefact, product or process that satisfies a perceived need. The perceived need will be something that is of economic benefit to a science industry, a company, even an individual, and thus good for the nation. To develop applications of science, students should have the opportunity to be creative and innovative in their technological solutions.

The assumptions within this line of reasoning are:
(i) that group skills and their associated attitudes can be learnt and transferred from one context to another;

(ii) that useful learning should be structured around relevant problems but in this case the relevance is a technological, economic relevance, not a personal and individualised relevance;
(iii) and that learning should include the opportunities to be creative and innovative.

In summary, vocational considerations support the use of problem solving in teaching and learning useful knowledge in meaningful situations. What knowledge is useful and what situations are meaningful is determined by an appeal to national needs, economic necessities and the good of society as a whole (though it is beyond the scope of this present work to explore different interpretations of the phrase ' the good of society).

D. The ideological

These considerations centre on the relationship between problem solving and the kind of society that schools can help to create. If the view is taken that schools can be agents of social change then the activities that children experience should enable them to learn the values and attitudes that are important in relation to the kind of society that is desired. According to Nott, the ideological case makes assumptions about present schooling (and problem solving) along the following lines: the majority of schoolchildren experience a science education that is boring because of the preponderance of didactic teaching methods and confirmatory practical work. It is esoteric and irrelevant in that it concentrates on theoretical science, using little of the children's own experience and with the content determined mainly by the needs and demands of higher education. There is little scope for pupils to develop or express their opinions or ideas. Consequently the majority of children do not develop a personal attachment to science. Science education is no different from other subject areas in that children periodically have to jump the examination hurdles and most children experience failure rather than success. In summary, the majority of children therefore experience a science education that is boring, irrelevant, too difficult and reinforces failure. This means that children may grow up not valuing education or science. They may see that science and its applications have social and political dimensions, but because of their own feelings of inadequacy in this field they would rather leave decisions to others. They feel that their own contributions could not have any worth or value.

If the desire is to build a society in which people do value their education, are not made to feel like failures and are able to develop and use capabilities in several areas of experience including the scientific, then, the ideological case continues, there is a need to alter the nature of schooling and consequently science education. This means that what is taught and learnt needs to change from present practice. The problem is serious. The 1994 DfEE survey "Science and maths: a consultation paper on the supply and demand of newly qualified young people." (16) noted that the proportion of 16-18-year-old students studying only science and maths was falling, from 30% in 1984 to 16.6% in 1993. The OFSTED review published in the same year was no more encouraging (167 and
Woolnough, writing on "What's wrong with school science?" (18), broadens the discussion:

> "The popularity of science in schools - or rather its apparent lack of popularity - continues to be a matter of public concern...Some of the most important factors that influence student choices have nothing to do with school, but are concerned with the way in which careers in science are viewed by society at large...many able and ambitious students perceive this and aim for jobs with greater financial rewards and higher status."

It follows that, although the experiences pupils have of science as a school subject are one contributory factor, the impact of the style of teaching and learning has to be seen against the background of broader sociological issues. In conclusion, ideological support for problem solving activities, especially those based on technological applications to realistic and relevant personal or social problems, is strongest where the emphasis is on providing tasks which are intrinsically motivating to students and where there is scope for opinions to be formed and discussed.

4. What are the purposes of problem solving in science education?

Educational purposes are expressed in student activities and so it is useful to enquire as to the problem-solving activities in which children should be involved or the experiences they should encounter in school classrooms/laboratories that are feasible for teachers to organise. Andy Howlett writing on Problem solving and the art of teacher maintenance (19) divided such activities into two distinct categories:

1. Problem testing, where pupils learn skills and concepts in lessons and are then asked to solve a problem as a method of evaluating the topic or assessing the level of skills/concepts learnt.
2. Problem learning, where pupils are confronted with a problem, for which they have no previous experience in school, that is designed to draw them into research and experimentation along desired curriculum lines. In finding a solution to the problem they will of necessity encounter and acquire the desired skills and concepts.

The first category is clearly closed in nature and the success of the pupil in giving the 'correct answer' yields a score which is interpreted as a measure of progress. He went on to identify the second category with 'Open-ended problem solving'. However, open problems are problems in which there are several solutions and/or methods of solution. The problems may be open in that people do not know an answer. e.g. What are the physical laws governing turbulent flow of a fluid? (although this may be near a solution!); or they may be open in that there are a variety of solutions which may require the consideration of many factors, e.g. choosing the site of a nuclear power station or designing safer bicycles . These factors may not just rely on scientific rationality but may ask people to question and articulate their values, attitudes and beliefs. Clearly Howlett has adopted an over-simplified taxonomy which can be subsumed into the more general taxonomy discussed next.

Pitt (20) made a strong case that the purposes of problem solving can be placed in the framework shown on the following page. The x-axis variable relates to the prior knowledge that the teacher expects the children to have. The y-axis variable indicates differentiation of the type of knowledge on the principle that there is a difference between 'know that' knowledge - the content - and 'know how' knowledge - the processes. The z-axis variable makes a statement about how the children are expected to work and/or the scope of the activities that they experience.

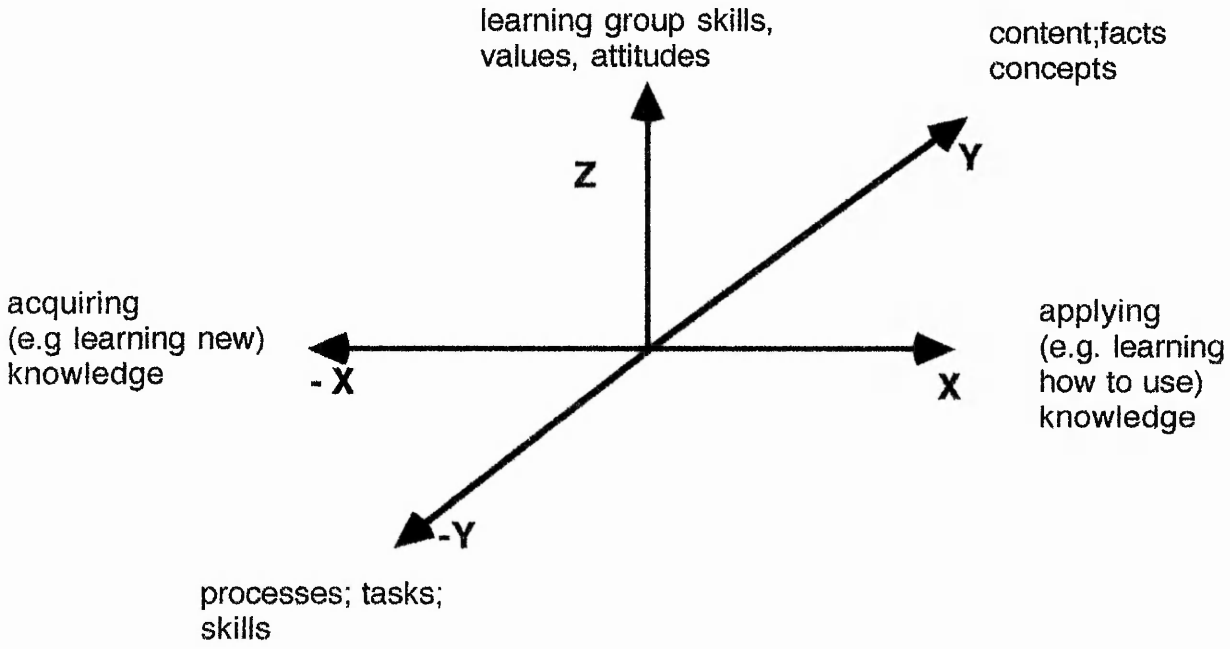


Figure 3

Where do problems now fit in this three-dimensional framework? Take, for example, the closed problem that has been presented about measuring the electrical resistance of a known length of wire of known material and thickness. What is the purpose of the problem? That depends upon the lessons that have preceded the presentation of a problem. For example, if it comes at the end of a unit of work on resistance and its measurement and it is intended that it is done as a group exercise then it may be placed in the framework shown below. Use of acquired concepts and processes is required. It is applying knowledge that the children are expected to have and the mode of working is to plan and execute the problem as a group. A small gain in new knowledge is expected in terms of finding out the value of the resistance of the wire and this would come into the 'facts' category on the y-axis. The relative importance of these dimensions could be marked as distances on the axes as shown below in figure 4. Then the areas bounded by these values could be mapped to give a visual representation as shown in figure 5.

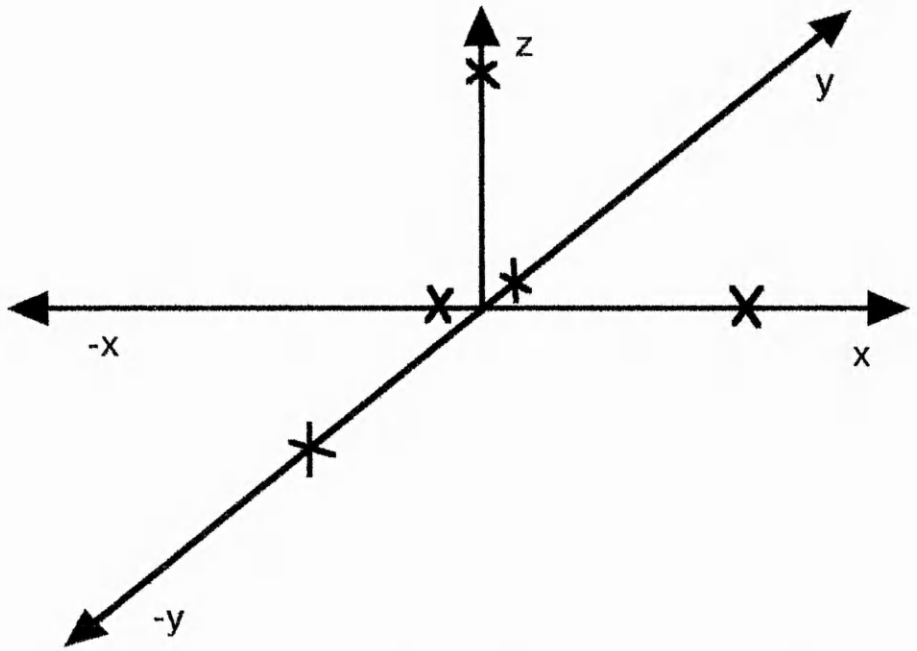


Figure 4

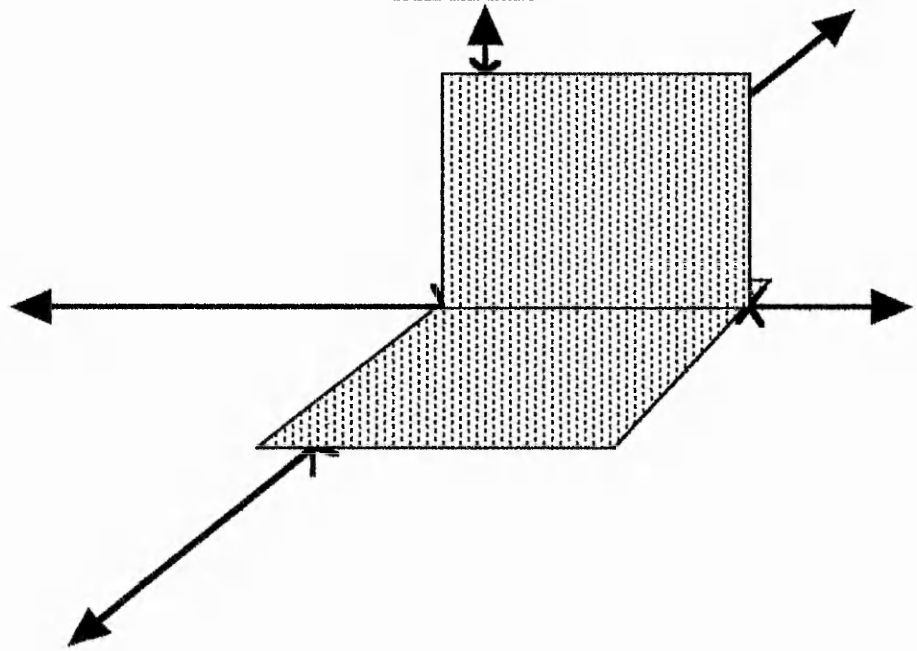


Figure 5

However, if the problem was presented as a way of teaching about resistance as an integral part of a unit of work, then the problem will shift towards the other end of the x-axis.

If it was presented as a problem where there were no expectations about the prior knowledge, then the purpose shifts to acquisition of knowledge rather than application of knowledge, as shown in figure 6.

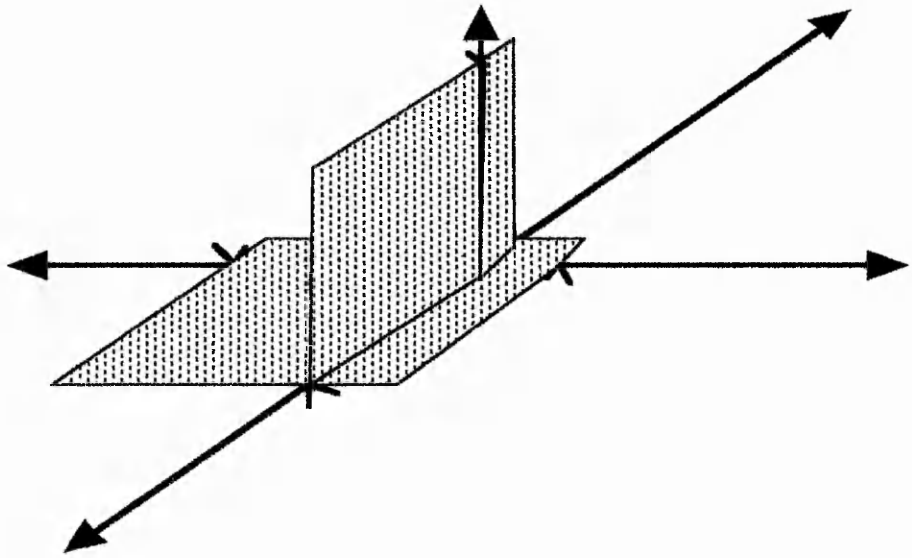


Figure 6

If the problem was presented as a question in a school test then it has no purpose in terms of learning group skills, new knowledge or values and attitudes. The purposes may be to see if the child can remember knowledge and gain increased mastery of specific revision and examination skills and processes. Such a theoretical problem could be represented as shown in figure 7.

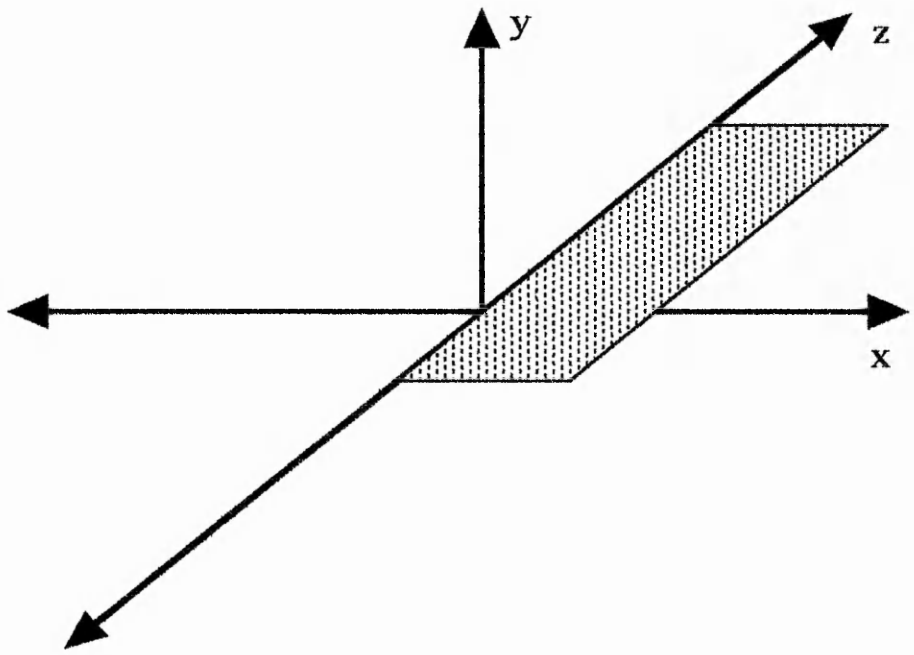


Figure 7

(Testing and reinforcing knowledge using tests which involve application to problems)

So, applying Nott's representation to the case of practical team problem solving, let us suppose that the task is to find whether the current flowing through a resistor bears any relationship to the applied potential difference. In this case, there may, for example be no requirements to demonstrate explicitly a knowledge of the concept of resistance, but pupils work in a team to apply previous knowledge e.g. using an ammeter and voltmeter, to acquire new knowledge based on an understanding of the concepts of current and potential differnce. The relative importance of these areas may be represented by the position on the appropriate axis, in which case the task now shifts to a new position shown in figure 8.

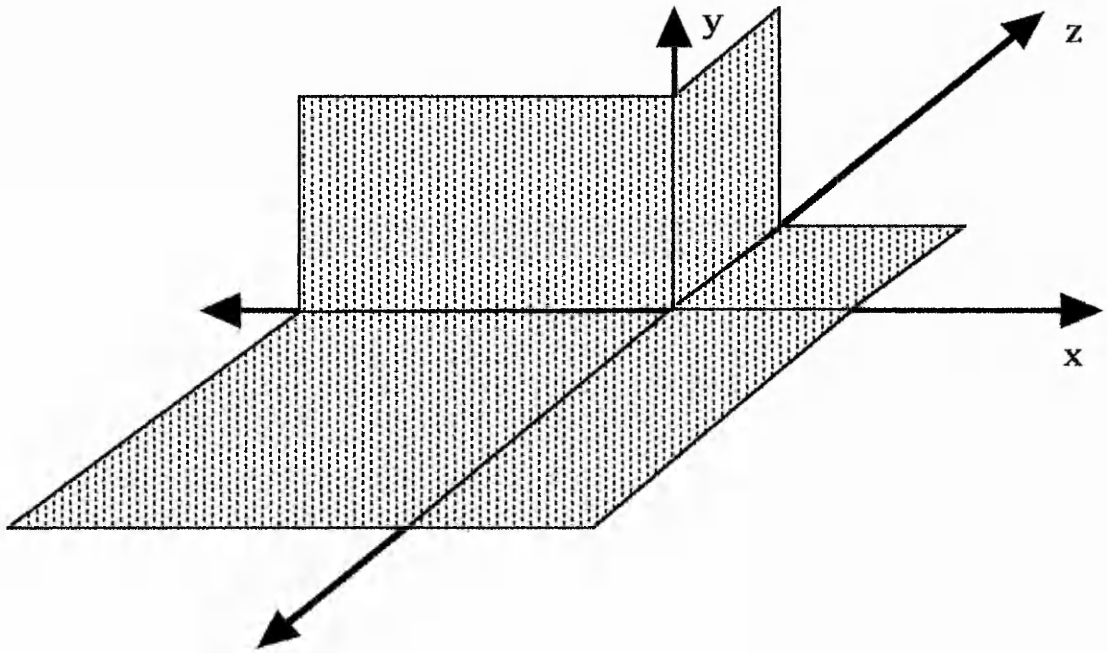


figure 8

Practical team problem solving using existing knowledge to tackle an unfamiliar problem

An advantage of this form of representation is that any given problem-solving activity can be described in terms of the relative weightings of the activities in which pupils will be involved. At the end of any stage in the science curriculum, it is then possible to superimpose the diagrams and gain a visual impression of which learning experiences are being emphasised. It is perhaps too simplistic to think in terms of a linear problem type

continuum when considering the purposes and methods of problem solving. Descriptions such as closed-open can be applied to problems but they do not provide a framework which teachers can use to talk about the educational purposes of problem solving. This framework therefore facilitates meaningful dialogue about professional practice and can also be used to ensure that children experience a variety of problem-solving exercises in a structured rather than haphazard way.

The role of discussion as an activity in problem solving

A major activity which underpins all problem-solving activities for pupils is the freedom to discuss their ideas and as such, address the issue of language across the curriculum which was raised in the Bullock Report. Students should be free to identify and initiate their own problems for enquiry, to express their ideas and to develop them into hypotheses, to test their ideas against relevant evidence. Such pupil discussions should allow opportunities for them to defend their ideas in the light of rational criteria and to bring their criteria to bear critically on the ideas of others. Even the ideas of the teacher cannot be safe from criticism and challenge if we accept this model and this has implications for pupil and teacher roles as discussed in a later section below. For the student, exposing one's ideas to peer group criticism can be threatening and it may be helpful to begin with purely creative activities. Brainstorming is a particularly unthreatening way of being creative within a group, but of course more sophisticated and disciplined group interactive work should also have its place and be developed once confidence in the process of problem solving has been established.

Summary

In this chapter, the main characteristics of, and rationale for, team practical problem solving have been described. Purposes have been examined and represented visually using a three-dimensional framework. This framework has been applied to the form of school practical investigations which were used in the intervention research in this work, to provide one description of the extended investigation working model. The next chapter completes the description by examining 'techno-science'.

Chapter 4

Evidence for a 'techno-science paradigm'

The model which is adopted as the basis for intervention research in this thesis is set in the framework of a 'techno-science paradigm' and so assumes a science-technology continuum. Therefore it is necessary at this point to establish the close relationship of science to technology with particular emphasis on key stage 4, prior to describing the model itself. The historical evidence for linking science and technology in the school curriculum has already been discussed and we shall now consider the nature of science and of technology in the context of the National Curriculum.

The SSCR in its 1983 proposals (1) suggested that there should be adequate opportunities for all students to

> ".....use their knowledge of science to design and develop solutions to technological problems, to test and evaluate those solutions and to cost such exercises".

In August 1988 the Science Working Group produced its proposals (2) and within these were statements cogent to this discussion of the relationship of science to technology in schools. For example:

(i) commenting on the nature of science:

> "2.1 We were asked to advise on the science curriculum throughout the years of compulsory schooling and on Technology in the primary years. We have therefore considered the nature of both scientific and technological activities, their distinct characteristics and their inter-relationship."

The Group produced a description of the nature of science:

> "2.2 Science is a human endeavour and in its current study we need to acknowledge its history and future. It is a continuous process by which individuals and groups develop an understanding of the physical and biological aspects of the world. It is a way in which reliable knowledge about the world is progressively established through the generation and testing of ideas and theories. Faced with a new phenomenon, the scientist uses existing ideas which may then be modified or rejected if they do not help to explain it. The results of this scientific endeavour are progressively more powerful ways of understanding the physical and biological world."

(ii) They went on to describe the nature of Technology:

> "Technology is a creative human activity which brings about change through design and the application of knowledge and resources. Technology involves drawing on human knowledge and resources in order to make things work, control things and alter the way they work. It is a means whereby mankind makes progress and society develops."

(iii) At first reading, these descriptions appear to have little common ground. However, the Group, in the section on the contribution of science to the school curriculum wrote (the bold type is mine):

> "2.3 Schools have an important role to play in helping children to understand the world they live in, and in **preparing them for adult life and work.** We are mindful of the value of our task in helping to equip these citizens of the next century with an education which should stand them in good stead in a world that will be very different from our own. We believe that science has an essential contribution to make in the following ways:
>
> i. Understanding scientific ideas: Scientists have developed a powerful body of knowledge about physical and biological phenomena. Science education should provide opportunities for all pupils to develop an understanding of key concepts and enable them to be used in unfamiliar situations. **To allow this to happen, pupils need to understand and explore their use in a range of contexts; the study of pure or formal science by itself can lead to ineffective learning by many pupils. Technological applications, personal health or the environment can often provide contexts through which scientific concepts can be more effectively introduced and developed."**

(iv) So there is support for linking science to its applications in technology, but apparently merely as a learning aid. However, if one explores the document further, there is more evidence of an interaction between science and technology in society, for example on page 6:

> "iv. **Understanding the contribution science makes to society** Pupils should be encouraged to study the practical applications of Science and Technology and the ways they are changing the nature of our society and our economy. They should be helped to explore some of the moral dilemmas that scientific discoveries and technological developments can cause. Science education should encourage all pupils to appreciate their responsibilities as members of society and give them the confidence to make a positive contribution to it."

This is perhaps the key to understanding the techno-science continuum. If one admits for the moment the different natures of science and technology in terms of strictly theoretical definitions, then it is at the point where these definitions enter the operating context of solving real problems concerned with human needs, that theoretical niceties become submerged in the realities of practice.

(v) Further clues to the continuum may be observed in other sections of the document. For example, section (vi) on appreciating the nature of scientific knowledge (p7):

> "Pupils should further their understanding of science by exploring the social and historical contexts of scientific discoveries. Through this they can begin to appreciate the powerful but provisional nature of scientific explanation, and the process by which models are **created, tested and modified** in the light of evidence. " (bold type mine).

These three key words form one span of the bridge between science and technology: Technology has often been described as essentially creative, involving testing designs and modifying them in the light of experience. Thus there is confluence in these areas of scientific and technological process. The ways in which these words are realised in practical activities will vary e.g. scientific activities create hypotheses, theoretical models (but can also involve resorting to physical material models e.g. chemical models of molecules) whilst technology focuses on creating artefacts or processes, but the creative process is shared in the two fields.

(vi) Going further, in the section on technology in the (primary) school curriculum (3):

> "2.5 From the wide range of valuable activities going on in primary schools, it is possible to draw out some of the features which distinguish or characterise technological activity :-
> - practical problem-solving,
> - designing and making,
> - using experiences, knowledge and skills from other subject areas;
> - investigation, innovation, and evaluation;
> - designing and implementing a system."

The essential nature of a subject does not depend on the age group of those being taught so it is valid and instructive to draw comparisons with the Programme of Study for Science Key stage 4: Model A (D.E.S. proposals 1991) where, included in the list of detailed provisions for scientific investigation was (4):

- promote invention and creativity;
- encourage detailed planning of the activity;
- encourage the use of secondary sources;

Now practical problem-solving must *per se* involve the promotion of invention and creativity, for how else does technology advance? Designing and making must involve detailed planning; and using experiences, knowledge and skills from other subject areas must encourage the use of secondary sources. This is not an isolated comparison for a similar exercise using the 1993 Key Stage 3 Pilot S.A.T. document in the section "What is an investigation?" has a list of requirements which investigations place on pupil activities, including:

> "• put together a sequence of investigative skills...into an overall plan for solving the problem;
> • define and develop the way they tackle problems;"

When commenting on the connections between science and technology, the 1988 proposals included (5):

"2.7 Although science and technology are closely linked, there are important differences in their purposes. Whereas science is concerned with the pursuit of reliable knowledge about the physical and biological world, technology is led by human needs and involves meeting those needs or solving identifiable problems. It is concerned with optimisation, and with balancing costs and benefits in any solution.

2.8 Clearly there are important connections between science and technology. During its history, science has drawn on technology in developing its instrumentation and techniques of enquiry. Significant discoveries have depended on the development of particular tools, materials and techniques. Conversely, in attempting to solve a problem to meet a need, whether it is designing a bridge for a particular site or finding ways of providing human communities with clean drinking water, technologists may draw on and use scientific knowledge. Technology, however, is more than applied science - it draws the knowledge it needs for solving problems from many disciplines."

The 1989 D.E.S. Orders for Science in the National Curriculum contained some significant remarks on the links between science and technology. The relevant section (6) is quoted in full to facilitate our discussion of its contents. Again, the bold type is mine and highlights points to be discussed in this work.

"SCIENCE, DESIGN & TECHNOLOGY

5.1 Technology is a creative human activity which brings about desired changes by making, controlling or improving the way things work through design and by using relevant knowledge and resources.

5.2 **Scientific and design & technological classroom activities may be difficult to distinguish.** Indeed, some teachers have been introduced to design & technology through practical science and vice versa. There are, however, important differences in style and purpose between the two. Whereas science is enquiry-led and concerned with the pursuit of better investigative

strategies and more reliable knowledge about the physical and biological world, design & technology is led by the desire to meet human needs and opportunities. Furthermore, design and technology needs to take a wide range of factors into account, optimising and balancing costs and benefits in any solution. **Clearly, there are important connections between science and design & technology: science draws on design & technology in developing its instrumentation and techniques of enquiry; significant discoveries have depended on the development of particular tools, materials or techniques.** Design & technology is more than applied science. Whilst drawing on the knowledge it needs for solving problems from a wide range of disciplines, it has judgmental aspects, such as:

- deciding what is worth doing and is achievable;
- generating and appraising possible solutions;
- reconciling conflicting demands;
- making decisions on the basis of imperfect information;
- achieving outcomes within constraints of time and cost."

This list provided a basis on which to distinguish science from technology, but begs the questions: do scientists not consider whether their objectives are worth doing? Do scientists not generate possible solutions - surely this is hypothesising? And what is evaluating such hypotheses in the light of measurements, if not appraising possible solutions? The reconciliation of conflicting demands involves similar skills to the decisions taken to prioritise the key independent variables within a set of variables. The whole scientific community continually builds theories on the basis of information which is incomplete - from models of prehistoric animals based on partial fossil remains to the range of neo-Darwinian evolutionary theories, to theories of the formation of the cosmos. Finally, how can it be supposed that scientists do not set out to achieve outcomes in research within the constraints of time and cost? So the list of supposed differences seems rather to achieve the opposite purpose of supporting a continuum.

The section on curricular coherence was more encouraging from a techno-science perspective, and acknowledged interaction and mutual support (bold type mine):

"5.3 ...The nature of the experiences which pupils engage in, their records of achievement and the needs which may arise in their pursuit of technological problems, will be useful for teachers engaged in the design and delivery of science courses. **The educational interaction of science and design & technology is powerful and each school will need to organise its curriculum so that the way in which design & technology interacts with science, as with other areas of the curriculum, allows both to capitalise on the support each gives the other. Teachers will need to take account of the pupils' perspective on how coherent this area of the curriculum appears.**

Co-ordinated planning during implementation, and common record keeping as the courses get under way and mature, are necessary parts of the process of delivering a coherent science and design & technology curriculum. " .

The key word is 'coherent' and the importance of this is recognised in the checklist given in the NCC's non-statutory guidance (1989) for the selection of learning experiences in science which includes the question:

> "Will the experience give opportunity to apply scientific ideas to real life problems, including those which require a technological solution?"

This defence of a techno-science paradigm concludes with a comparison of the Orders for Technology which emerged in 1990 and a second edition of the science orders (December 1991).

As illustrated in the following table, there are large areas of common ground in the stated aims of technological process and scientific exploration. For example:-

- pupils should explore their environment in both, seeking on the one hand theoretical understanding, and on the other opportunities for meeting human needs (by applying theoretical understanding);
- in science, pupils should adopt a systematic approach in which the purposes and objectives of the investigation are clear, whilst in technology a design specification is required. But the similarity becomes clear if one goes one stage further: scientific exploration involves pupils in planning and then carrying out a procedure which they may modify in the light of

experience, and technology involves a design proposal, then working to a plan which may also be modified during its execution;

- both require pupils to draw upon their existing knowledge;
- whilst in science education pupils evaluate evidence (and indeed at the highest levels evaluate the entire investigation and the scientific hypotheses, theories, models and other knowledge associated with the investigation), in technological education they are evaluating processes, products and their associated effects.

A comparison of the overall aims of scientific exploration and technological activity in the statements of attainment for science and technology (DES Orders for Science 1991; DES Orders for Technology 1990) provides further examples of continuum .
Common concepts, cognitive abilities or processes are shown in italics (mine) in the table below.

Science attainment target 1 Scientific exploration- aims	Technology attainment target 1 Identifying needs and opportunities - aims
(A) Pupils should develop the intellectual and practical skills which will allow them to explore and investigate the world of science and develop a fuller understanding of scientific phenomena, the nature of the theories explaining these, and the procedures of scientific *investigation.*	Pupils should be able to identify and state clearly the need and opportunities for design and technological activities through *investigation* of the contexts of home, school, recreation, community, business and industry.
	Technology attainment target 3 Planning and making - aims
(B) Aim (A) should take place through activities that require a *progressively more systematic and quantified approach* which develops and draws upon an increasing knowledge and understanding of science.	Pupils should be able to make artefacts, systems and environments, preparing and *working to a plan and identifying, managing and using appropriate resources*, including knowledge and processes.
	Technology attainment target 2 Generating a design - aims
(C) The activities of aim (B) should encourage the *ability to plan and carry* out investigations in which pupils : i) ask questions, predict and hypothesise; ii) observe, measure and manipulate variables;	Pupils should be able to generate a design specification, explore ideas to *produce a design proposal and develop it into a realistic, appropriate and achievable design.*

	Technology attainment target 4 Evaluating - aims
iii) interpret their results and *evaluate* scientific evidence	Pupils should be able to develop, communicate and act upon an *evaluation* of the processes, products and effects of their design and technological activities and of those of others, including those from other times and cultures.

Some of the key words and phrases shown in italics may seem *prima facie*, to be dissociated from one another, but such is not the case. For example,
(a) the role of the design specification in Technology is to define the characteristics of the process or device in terms of how it will meet the stated need. It therefore provides a framework for the selection of materials and manufacturing processes within economic and environmental constraints. Although there is no exact equivalent of a design specification in science, there are some features which are shared with an hypothesis:
(i) both are a response to a human need - for science it is understanding; for technology it is to enable something to be done better;
(ii) both provide a structural framework within which subsequent work is carried out;
(iii) both set the overall objectives and purpose;
(iv) both involve constraints, limitations in scope, purpose and applicability. The set of initial questions which an hypothesis sets out to answer and an investigation seeks to check, may be compared with the set of criteria which have to be met by a design specification and within which a design proposal must be framed.

(b) Similarly a design proposal shares features with an investigative strategy:
(i) both involve detailed planning, whereby knowledge and understanding are marshalled to produce a practical method of checking an hypothesis (meeting a design specification) within the constraints of available apparatus, time, cost, materials etc.
(ii) both may require modification in the light of experience;
(iii) both involve taking multiple factors into account, sorting the factors into priorities and providing justifications for the decisions.

With these paired similarities in mind, the similarity comparisons of the above table are more apparent.

In the D&T Working Group interim report, para.1.35, the group writes

> "Good communication skills together with confidence in an ability to solve problems... have proved as important in determining the success of technological activities as possession of special knowledge and techniques."

It is thus clear that problem solving is an activity which is central to both scientific and technological activity.

A further area of interest in the science-technology continuum is information technology and the Orders for Science 1991 for AT1 level 3 include the explicit reference:

> " offer opportunities to develop computer skills...during experiments."

One may also infer an implicit link with I.T. in:

> "encourage the interpretation and evaluation of collected data..."

and

> "encourage the search for patterns in data..."

Similar inferred applications of I.T. to data handling in science are evident at higher levels where opportunities abound for data logging and computer analysis.

The Non-statutory guidance for Information Technology Capability (1990) suggests that I.T. can be used to report a science investigation (page C6) and the use of databases (C8) is an important skill in scientific enquiry. The guidance states

> "Pupils will continue to use simulations to support investigation (e.g. they might compare data from experiments with those from a computer model and refine the model to match results from their investigations)."(C10).

In the same document there is the concession that

> "It may be difficult to distinguish between scientific activities and those in design and Technology"(C10)

When the 1991 Order for Science in the National Curriculum is read alongside its counterpart in technology, from levels 4 to 10, then the closeness of the relationship becomes evident, and is shown in the tables below (on the following pages for completeness of display).

Summary

This section (chapters 2 to 4) has reviewed the psychological processes associated with problem solving and examined scientific problem solving in the context of the work of leading educational psychologists. The nature of problem solving tasks has been described and reasons given for their inclusion in science education. Significantly, for the purposes of this work, the dichotomy which is sometimes perceived to exist between science and technology has been bridged, a techno-science paradigm established and practical problem solving (investigation) in science has been shown to form a continuum with activities in technology, requiring similar teaching and learning styles.

It has been established that team techno-science practical problem solving is a learning experience which is worthy of inclusion in a national curriculum for science. Furthermore, in order that pupils may have access to the full range of opportunities in this type of experience, an adequate period of time, usually well in excess of a single or even a double science lesson, should be allocated.

Thus, in this thesis, a working definition of the term "extended investigation" is: team techno-science practical problem solving requiring well in excess of a single or even a double science lesson.

Such a definition is consistent with the level statements of attainment of the Orders for Science 1989 and 1991 (implicit in the examples of investigations provided in guidance to teachers) where for example, in the 1989 Orders, levels 9 and 10 of attainment target 1 required the use of extended investigations. This type of investigation is the subject of this piece of intervention research work.

The next stage of this work explored how the teaching and learning styles associated with extended investigations were employed in some secondary schools within an network called E.M.S.T.A.R. (East Midlands Science Teachers' Action Research). This group was established in response to a demand by teachers expressed in April 1991 at an ASE Regional Symposium. A programme of intervention enquiry was used to establish what (if any) particular learning advantages attached to the use of extended investigations.

It should be noted that the requirement for extended investigations was dropped from the 1994 SCAA Draft Proposals:

> "The higher level descriptions remove the present demand for extended pieces of work." (7)

Consequently, the outcomes of this work provide a source of comment on the 1994 decision to exclude extended investigations from the Science National Curriculum Orders.

Chapter 5
The hypothesis to be tested.

The purpose of this chapter is to describe how an hypothesis was developed to meet aim 4 of this work (to design and evaluate a research instrument for investigating practical work for use in the school science laboratory learning environment). The hypothesis was formulated to provide a test of the educational value of using the techno-science paradigm to provide a framework, not only for extended investigations in science, but also, in a wider curricular context, for extra-mural activities such as work experience where there is the opportunity to relate classroom science to industrial technology.

From the foregoing discussion, two principal issues form the basis for the hypothesis:
Firstly, in the area of learning scientific knowledge, Kelly (1) and Driver (2), emphasise the need to respect pupils' natural curiosity and drive to explore the world around them. Polanyi (3) when differentiating between explicit knowledge and tacit knowledge, argues that scientists rely very largely on tacit knowledge in the way they work. Ravetz (4) follows this line, and speaks of the way that a scientist works 'as a craftsman'. He writes that schools tend to over-emphasise academic knowledge, and under-emphasise the instinctive, tacit knowledge acquired and applied by the engineer and in the 'personal activity of a creative scientist'.

Secondly, with respect to scientific method, too frequently, experiments are used as quick-fix verifications of well-established scientific laws and theories. The process of genuine enquiry is subservient to the objective of contriving simplistic and cheap 'proof' experiments. This, I contend, is an unsatisfactory procedure. The reality is that, before entering a science laboratory, students will have had a number of years of experience of learning to cope with such things as force, energy, gravity, electricity, heat and light. Many students have developed quite sophisticated models to make sense of the world around them, and they will not readily give these up under the influence of experiments in the laboratory which may, or may not, fit well into their existing framework. For instance, many students come to the topic of electricity with the firm belief that electricity gets used up as it goes round the circuit - therefore the current decreases. This notion will have been formed by learning that batteries go flat after some use, that household electricity bills have to be paid regularly because

the electric cooker has used up electricity which was produced by the power station; that even the power station uses up its coal supply to make electricity. It is all very reasonable. It may well be reinforced if the primary school has put across the idea that 'electricity is a form of energy'. It will take more than a few ambiguous experiments with a circuit board to alter this until the student has sufficient intellectual maturity to differentiate between electrical energy, electric charge, electric current and potential. As Driver points out, in holding to existing paradigms and in viewing the world through them, students are acting just like scientists (5). Quoting Planck she says, 'new theories do not convert people, it's just that old men die'. This is rather pessimistic, but we do need to be aware of the preconceptions that they bring into the laboratory and build on them. To use Ausubel's words, 'The most important factor is what the learner already knows. Ascertain that and teach accordingly'.

It is the contention of this thesis that pupils' experience and understanding of everyday life is consistent with a techno-science paradigm. If this is what pupils already know, and if they understand everyday phenomena in terms of techno-science continuity rather than dichotomy, it should be the best foundation for building further knowledge and understanding. Teaching approaches which respect this paradigm should therefore, according to constructivism, yield superior learning. Consequently, the hypothesis of this research centred on the idea of a techno-science paradigm which forms a framework for learning experiences both inside and outside the classroom. The hypothesis was then expressed in terms of testable predictions.

Hypothesis

(i) Pupil attitudes should be enhanced and knowledge gains accelerated by using learning experiences framed within techno-science.
(ii) Pupil performance in scientific process skills should be superior after working on techno-science investigations.

A model for extended problem-solving practical scientific investigations has been developed for the purpose of testing these hypotheses and will now be described.

Chapter 6

A suggested model for extended investigations

The purpose of this chapter is to describe how the third aim of this work (to devise a working model of team problem-solving investigative practical work, set in the 'techno-science' context of real industrial problems, as the basis for intervention research in schools) was achieved by devising a model of a form of techno-science investigation which would enable the hypothesis to be tested. In chapter 4 of this thesis, a working definition of the term "extended investigation" was devised: team techno-science practical problem solving requiring well in excess of a single or even a double science lesson. To express this definition in curricular materials, such extended investigations would have to satisfy criteria derived from the previous chapters of this work, as well as being consistent with the description of investigations given in the National Curriculum, if teachers were to feel comfortable about setting aside teaching time and allowing their pupils to participate in field tests.

I am now in a position to describe a model for extended investigations by drawing together the principles which have emerged in the previous sections in this work: historical development of practical science, the ideas of the main schools of thought in educational psychology and the approach to experimental and investigative science set out in the various National Curriculum Orders for Science from 1989 to 1995. The first stage in the design of the research instrument was to set out criteria useful in selecting particular learning experiences for the pupils. At the time of designing the questionnaire, only the 1989 and 1991 Orders, together with the Non-statutory Guidance (NSG) which accompanied the 1989 Order, were available. Some of these criteria are clearly illustrated in the 1989 NSG and short sections are quoted below. Where appropriate, these are supplemented by passages from later Orders and from other sources where the Orders did not cover the full range of principles developed in this present work.

Criteria on which the extended investigation model was based

Of the ten criteria listed, seven were exactly those found in relevant statements in the National Curriculum documentation, whilst the other three reflected educational theory discussed in previous chapters of this work. Each criterion was defined by reference to the appropriate literature, as quoted below.

(i) Extended investigations use relevant contexts.

A key statement is found in the section on learning science in the 1989 NSG:

> "Skills of investigation do not develop in isolation from the subject matter or ideas being used. In making observations, hypothesising or planning an investigation, there is always a specific problem. We know that the way pupils use their investigative skills depends on their familiarity with the context in which they are working...
> ...If the context in which science is taught is chosen carefully, pupils can come to appreciate the relevance of the subject to everyday life. This adds interest and motivation and will lead to a deeper understanding of the importance of science in the economy and the quality of life for citizens."

Also in the 1989 Orders in Programme of study: Key Stage 3

> "Pupils should be encouraged to develop their investigative skills and their understanding of science through systematic experimentation and investigations which are set within the everyday experience of pupils and in wider contexts, and which require the deployment of previously encountered concepts and their investigative skills to solve practical problems."

(ii) Extended investigations develop peer group communication.

This is encapsulated in the 1989 NSG in the section on learning science:

> "Communication with others plays an important part in the learning process. Their learning is supported and extended through discussion with peers and adults. Through talk and informal writing they are able to make their ideas clearer to themselves as well as making them available for reflection, discussion and checking."

In the section on teaching:

> "Will the experience give pupils the opportunity to:
> • work co-operatively and communicate scientific ideas to others?"

(iii) Extended investigations reflect real research science and develop the learning skills used by scientists.

In the section in the 1989 NSG on what it means to be scientific:

> "Young people are learning about new things and developing skills, which, in time, will give them access to further areas of knowledge.

Sometimes pupils, working under the direction of their teacher, do actually carry out scientific research. School science is a reflection of science in the 'real' world, where scientists learn from each other and extend the boundaries of knowledge by research."

In the section in the 1989 NSG on teaching:

"Will the experience give pupils the opportunity to:

- develop scientific strategies and skills;
- develop attitudes appropriate to working scientifically;
- discuss the ways in which scientists work?"

In the 1991 Orders Programme of Study for AT1, the three key criteria associated with practical scientific investigations were:

- ask questions, predict and hypothesise
- observe, measure and manipulate variables
- interpret their results and evaluate scientific evidence.

The major skills intrinsic to experimental and investigative science were listed in the 1994 Draft Proposals by SCAA and in the 1995 Orders as:

"1. Planning experimental procedures.
2. Obtaining evidence.
3. Analysing evidence and drawing conclusions.
4. Evaluating evidence."

<u>(iv) Relate to pupil's interests and be designed to increase motivation.</u>

In the section in the 1989 NSG on learning science:

"Pupils' attitudes affect the willingness of individuals to take part in certain activities, and the way they respond to persons, objects or situations. Willing participation is an important ingredient of effective learning."

In the section in the 1989 NSG on teaching:

"Will the experience:

- stimulate curiosity;
- relate to the interests and everyday experiences of the pupils;
- appeal to both boys and girls and those of all cultural backgrounds?"

<u>(v) Develop appropriate attitudes.</u>

In the section in the 1989 NSG on learning science:

"The following attitudes and personal qualities are important at all stages of science education:

- curiosity;
- respect for evidence;
- willingness to tolerate uncertainty;
- critical reflection;
- perseverance;
- creativity and inventiveness;
- open mindedness."
- sensitivity to the living and non-living environment;
- co-operation with others."

In the section in the 1989 NSG on teaching:

"Will the experience give pupils the opportunity to:

- develop attitudes appropriate to working scientifically;
- develop an understanding of the relationship of scientific ideas to spiritual, ethical and moral dilemma?"

(vi) Cross subject boundaries, particularly between science and technology.

In the section in the 1989 NSG on teaching:

"Will the experience give pupils the opportunity to:

- apply scientific ideas to real-life problems including those which require a design & technological solution?"

In the section in the 1989 NSG on Science, Design and Technology:

"The educational interaction of science and design & technology is powerful and each school will need to organise its curriculum so that the way in which design & technology interacts with science, as with other areas of the curriculum, allows both to capitalise on the support each gives the other. Teachers will need to take account of the pupils' perspective on how coherent this area of the curriculum appears. "

(vii) Require that solutions be presented orally and in written formats.

This is one of the five key abilities listed in the 1989 version of AT1:

"v. communicate exploratory tasks and experiments."

It is placed fourth in a similar list in the 1995 Key Stage 4 Programme of Study:

> "Pupils should be taught to...use a wide range of scientific and technical vocabulary..."

A particularly useful statement was provided in the Programme of Study for Key Stage 2 in the 1991 DES Orders:

> "Communication: pupils should have opportunity...to develop and use communication skills in presenting their ideas and in reporting their work to audiences, including pupils, teachers, parents and other adults. In giving an account orally or in writing, they should be encouraged to present information in an ordered manner..."

(viii) Provide active imitation of the work of professional scientists.

Kelly (1) and Driver (2), would see students as scientists in their natural way of working; each naturally motivated to explore their world and to seek to interpret it for themselves and then make sense of it. The fact that all students do not always show this motivation to act as enquiring scientists in school laboratories may indicate more about the artificial and inhibiting nature of school science lessons than about the students' lack of scientific potential.

Increased motivation may also arise from respecting the pupils as learners and involving them actively. Although there is in a sense public knowledge in science, students need actively to construct their own personal awareness and meaning. Osborne and Wittrock (3) state the case clearly when speaking of the generative learning model of the pupil:

> "The brain is not a passive consumer of information. Instead it actively constructs its own interpretations of information, and draws inferences from them . . . to learn with understanding a learner must actively construct meaning. The successful learning of scientists' ideas is as much a restructuring of the way learners think about the world as it is the accretion of new ideas to existing ways of thinking."

(ix) Develop explicit knowledge and tacit knowledge

Polanyi (4) spoke of explicit knowledge and tacit knowledge, the explicit knowledge being articulated and cognitively assimilated into consciously formed theories, while tacit knowledge was never consciously articulated but was acquired directly through our senses and 'held' in readiness for

more direct application. He argued that scientists rely very largely on tacit knowledge in the way they work. Ravetz (5) followed this line, and wrote of the way that a scientist works 'as a craftsman'. Schools tend to over-emphasise academic knowledge, assumed to be the foundation stone for the pure scientist, and under-emphasise the instinctive, tacit knowledge acquired and applied by the engineer and in the 'personal activity of a creative scientist'. In so doing, we fail to tap an enormous pool of abilities among our young people. We need to emphasise the value of both explicit knowledge and tacit knowledge in our teaching. One of the values of students gaining concrete experiences through practicals is the direct gain of obtaining first-hand knowledge of the materials, of getting 'a feel for the phenomena'.

(x) Avoid apparatus complexity overload.

Whereas it is important to choose real-world contexts for investigation, reality can have the effect of distracting pupils away from the 'simple' elegance of the underlying concept. This is so often the case with practical work designed to illustrate a basic concept or principle, when students get so enmeshed in the detail, in the measurements, in the incidentals of the experiment, that they lose sight of the underlying purpose. The distracting clutter of reality presents a real hindrance to the search for patterns, whether students are trying to make sense of the world in which they live or of the experiments in the school laboratory. Johnstone and Wham (6) described the students doing practical as being in a 'state of unstable overload'. They suggest that learning is severely hindered when the working memory is overloaded with incoming data. Evidence from the Assessment of Performance Unit tests (7) shows that students can often deduce principles more confidently if they are not cluttered up by the scientific flotsam of experimental detail and often inaccurate data.

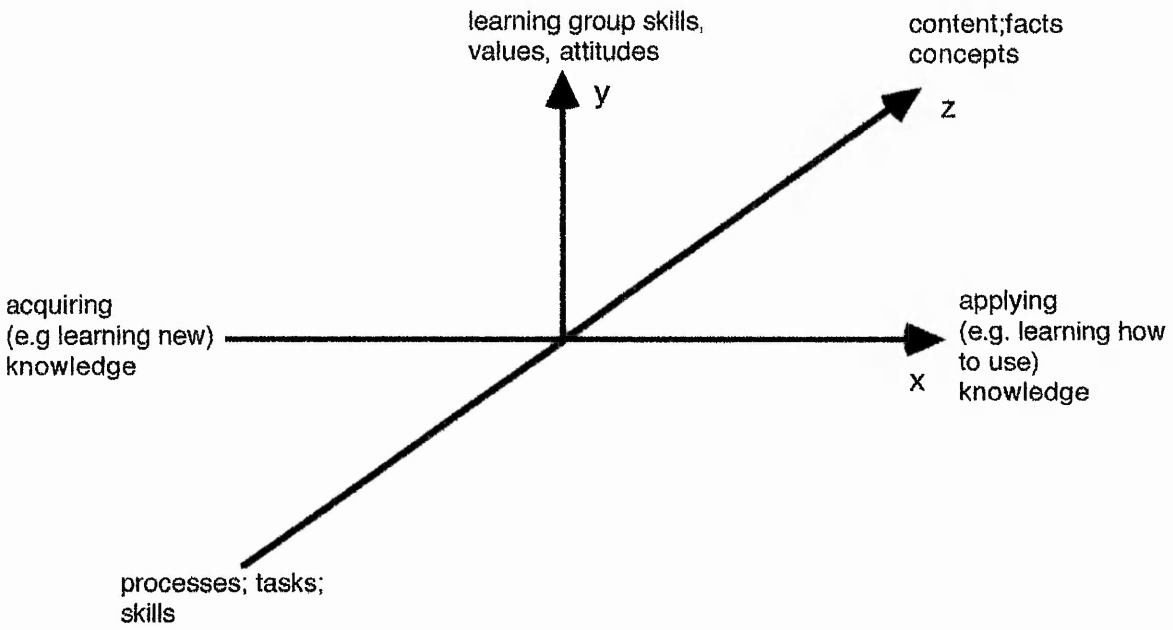
These criteria find full expression in problem-solving practical investigations which relate school science to real-world contexts such as industrial, technological or research laboratory. There are many examples of such extended investigations, in addition to those developed by this author in the 1980's. Such investigations have been part of school science for decades. For example a particularly interesting one was described by Woolnough (8) as long ago as 1972.

Summary of criteria for working model of extended investigations used in this work

1. Use relevant contexts.
2. Develop peer group communication.
3. Reflect real practical science and develop the learning skills used by scientists.
4. Relate to pupil's interests and be designed to increase motivation.
5. Develop appropriate attitudes.
6. Cross subject boundaries, particularly between science and technology.
7. Require that solutions be presented orally and in written formats.
8. Active imitation of the work of professional scientists.
9. Develop explicit knowledge and tacit knowledge
10. Avoid apparatus complexity overload.

The final stage before designing research instruments using the model, was to map these criteria on Nott's framework to enable the form of extended investigations to be visualised in terms of learning and applying knowledge, processes, tasks, skills, concepts, facts, values, attitudes and groups skills.

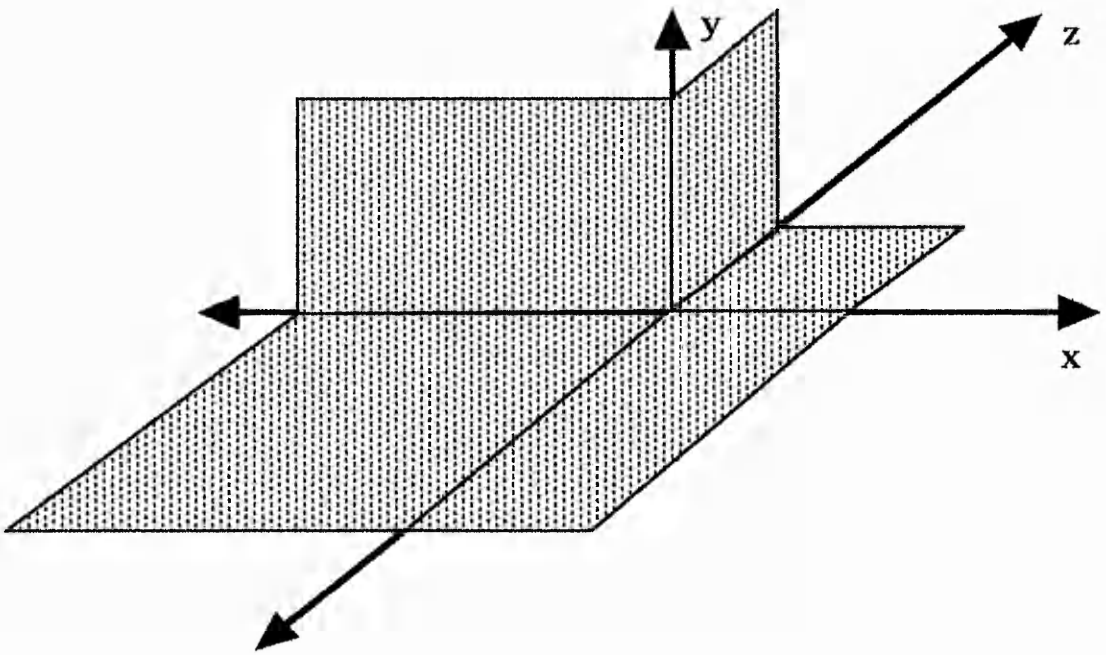
Returning to Nott's framework:



The 10-criteria model for extended investigations which has been developed as the basis for intervention research for this work, can be represented on to the framework using the following table which shows mapping of criteria to Nott's axes.

EXTENDED INVESTIGATION CRITERIA	NOTT'S AXES
(i) Use relevant contexts.	not a learning objective
(ii) Develop peer group communication.	Z, -Y
(iii) Reflect real practical science and develop the learning skills used by scientists.	- Y
(iv) Relate to pupil's interests and be designed to increase motivation.	not a learning objective
(v) Develop appropriate attitudes.	Z
(vi) Cross subject boundaries, particularly between science and technology.	X
(vii) Require that solutions be presented orally and in written formats.	- Y
(viii) Actively imitate the work of professional scientists.	Z
(ix) Develop explicit knowledge and tacit knowledge.	Y and -Y
(x) Avoid apparatus complexity overload.	not a learning objective

It is clear that extended investigations lead to pupils acquiring new explicit knowledge, but the weighting given to this aspect will depend on the investigation, and a typical extended investigation might have a map like the one shown on the following page, whereas the ones used for the intervention research will have slightly different shapes.



Summary

The criteria for extended investigations have been defined and the typical form of such investigations illustrated three-dimensionally.

However, the precise form of each extended investigation was not important to this work. It was not part of this piece of research to test Nott's approach, nor establish the precise effect on pupil learning of the different emphases occurring in different investigations.

Extended investigations were used in this work as one technique (amongst others) to test the hypothesis, and as such, provided criteria which could be related to teaching and learning styles. These distinctive styles were then used to construct an instrument to provide statistical information - the questionnaire described in the next chapter.

Chapter 7
Research Methodology
(i) Designing the principal research instrument

The purpose of this chapter is to describe how the fourth aim of this work was achieved by devising and evaluating a questionnaire to match the model form of techno-science investigation to actual questions in the principal research instrument which would enable the hypothesis to be tested.

The research context.

The educational climate at the time of the research programme was barely conducive to carrying out detailed surveys of teaching and learning. A significant additional administrative loading on science teachers (directly resulting from the introduction of the National Curriculum in science in 1989, and the changes made in 1991) had produced a degree of negativity towards detailed recording of pupils' progress and form-filling, which could have jeopardised the research programme. Yet, in order for the research work to have significance, the measurements would have to be large in number, involving many pupils and their teachers. To facilitate this, it was essential to have the co-operation of busy teachers. This dilemma was resolved in two ways:

Firstly a small research group was set up - East Midlands Science Teachers' Action Research (EMSTAR) - as a direct outcome of a Regional Symposium of the Association for Science Education (ASE) held on April 13th 1991 at the former Nottingham Polytechnic, which the present author chaired and delivered a keynote address. Initially, twelve teachers representing primary, special and comprehensive schools and a college of further education, formed the steering group of EMSTAR and assisted in the pilot field trials, feedback, evaluation and full field trials. It was the opinion of this group that intensive techniques such as teacher interviews, pupil interviews, classroom observation and video recordings would not be appropriate at that time. Preference was shown for a questionnaire approach.

Therefore, secondly, it was decided to develop a set of convenient questionnaires which could be used quickly and easily to obtain a snapshot of teachers' and pupils' perceptions of the science laboratory environment, teaching and learning styles. The questionnaires would be designed to

require not more than ten minutes for completion, to minimise the intrusiveness of the research activity on normal classroom procedures and so encourage participation. The questionnaires were also designed to be user-friendly in style, presentation and language. It was pleasing that this strategy was successful and the number of returned questionnaires was high. These returns number nearly 1000 and are bulky, so have been bound under a separate cover from this thesis.

Designing the pupil questionnaire

Following a review of recent work to develop questionnaires for use in school science lessons, it became clear that, over the past 25 years, considerable work had been done in Australia to research classroom environments to address questions relevant to the present work. They had, for example, investigated whether a classroom's environment affected student achievement and attitudes; whether teachers can conveniently assess the climates of their own classrooms and respond to these assessments by appropriate changes; whether teachers and their pupils perceive the same classroom environments similarly; and the impact of a new syllabus or teaching method on classroom environment. Work in this field had been carried out by Fraser in 1986(1), 1989 (2,3) and by Fraser and Walberg in 1991 (4).

Fraser, Giddings and McRobbie, had published on the topic in 1991 (5). Fraser and Tobin had published in 1991 (6). Fraser et al. had devised a questionnaire in 1990 (7) which was designed especially for laboratory classes. In the light of field tests, this instrument had been refined. Fraser, Giddings and McRobbie, when writing on 'Assessing the Climate of Science Laboratory Classes' in Australia, 1992, had commented (8):

"... because research has not been comprehensive, we simply do not know enough about the effects of laboratory instruction upon student learning and attitudes."

In the same research bulletin, an improved version of their earlier pupil questionnaire was presented, and provided a possible instrument for use in the present work. However two steps had to be undertaken: first, the quality of their questionnaire had first to be evaluated; and second, their questionnaire would have to be adapted to suit the purpose of this research. As to the first, Fraser reported that a review of the literature was undertaken to identify dimensions that were considered important in the unique environment of the science laboratory class. Guidance in identifying

dimensions also was obtained by examining all scales contained in existing classroom environment instruments for non-laboratory settings - Fraser, 1986. By interviewing numerous science teachers and students at the upper secondary and university levels and asking them to comment on draft versions of sets of items, an attempt was made to ensure that the questionnaire's dimensions and individual items were considered salient by teachers and students. In order to achieve economy in terms of the time needed for answering and scoring, the questionnaire was designed to have a relatively small number of reliable dimensions - 5 - each containing a fairly small number of items - 7.

Furthermore, reliability and validity were evaluated. A set of items was written and passed through several successive revisions based on reactions solicited from colleagues with expertise in questionnaire construction and science teaching at the secondary and higher education levels. Careful attention was paid to making each item suitable for measuring both actual and preferred classroom environment. A series of item and factor analyses reported by Fraser, Giddings and McRobbie, 1991 was used to improve the preliminary form and obtain a 35-item final form. Information about the reliability of the questionnaire dimensions was reported by Fraser, Giddings and McRobbie for the Australia-only sample, which consisted of 1875 senior high school students and 298 university students, described below. As well, reliability was been estimated for the larger six-country sample (Australia, USA, Canada, England, Israel, Nigeria) of 3727 senior high school students and 1720 university students also described below.

Schools/ universities	Country	SAMPLE SIZE Students	Classes
schools	Australia only	1875	111
	all 6 combined	3727	198
universities	Australia only	298	24
	all 6 combined	1720	71

The dimensions chosen for their questionnaire were:

Dimension name	Description
Student cohesiveness	Extent to which students know, help and are supportive of one another
Open-endedness	Extent to which the laboratory activities emphasise an open-ended divergent approach to experimentation
Integration	Extent to which the laboratory activities are integrated with non-laboratory and theory classes
Rule clarity	Extent to which behaviour in the laboratory is guided by formal rules
Material environment	Extent to which the laboratory equipment and materials are adequate

When the questionnaire was administered to a sample consisting of 516 senior high school chemistry students in 56 classes in Queensland, reliabilities (alpha coefficients) for class means were 0.80 for Student Cohesiveness, 0.80 for Open-Endedness, 0.91 for Integration, 0.76 for Rule Clarity and 0.74 for Material Environment. These values indicated that the questionnaire had satisfactory reliability for dimensions containing only seven items each.

On the basis of this evidence, the present author decided to adopt the Australian questionnaire, retaining appropriate dimensions but devising others which matched the hypothesis and stated objectives more closely. The seven-item structure was retained. However, it was recognised that the reliability and validity of the new dimensions could not be tested in the available time scale for this work. Therefore it was decided to adopt a trend approach where the same questionnaire would be administered to the same pupils on different occasions, separated by a period of several months, and the score differences used rather than absolute scores.

Construction of the pupil questionnaire

Certain precautions were taken to improve reliability:

- In order to ensure that any pupil bias towards positive responses i.e. in a way which they thought might give the 'right answer', a reversal procedure was used i.e. some questions (shown in underlined bold type below) were stated as opposites and the scores were reversed.
- Problem-solving was repeated in two sub- sets, (a) and (b) for two reasons: Firstly this is the principal area of interest in this work, and secondly the questions were original to this present work and untrialled.
- Checks were made of the consistency of respondents. This was considered to be more necessary with pupil responses. Consequently two sub-sets of questions were included on the pupil questionnaire:

Sub-set (a) comprised questions 1,6,11,16,21,31. These questions studied social cohesion which was an area already well-evaluated by Fraser et al. and a factor having a strong bearing on the teamwork required for group problem solving. Sub-set (b) comprised questions 4,9,14,19,24,34 and were concerned with safety rules and procedures - a close derivation of Fraser's rule clarity. Teacher consistency was also checked to a lesser extent through pairing questions 2 & 30, 28 & 32 and 1 & 22.

Furthermore, the present work did not include amongst its aims a study of integration or the material environment, but was principally concerned with practical problem solving investigations. The salient features of such investigations described earlier in this thesis, the literature on practical work on schools and the teaching and learning styles identified in the sections on science and technology, together with the evidence from psychology, were used to construct two dimensions to replace integration and the material environment. Consequently the questionnaire devised by Fraser et al. was re-designed as follows:

STUDENT COHESIVENESS

This was evaluated using questions 1, **6**, 11, 16, 21, **26**, 31.

OPEN-ENDED ACTIVITIES

This was evaluated using questions **2**, 7, 12, 17 ,22, **27**, 32.

PROBLEM-SOLVING(a)

This was evaluated using questions 3, 8, 13, **18**, **23**, 28, 33.

RIGIDITY AND RULE CLARITY

This was evaluated using questions 4, **9**, 14, 19, **24**, 29, 34.

PROBLEM-SOLVING(b)

This was evaluated using questions 5, 10, 15, 20, 25, 30, 35.

The strongest positive response to the item would give a score of:

Student cohesiveness	7
Open-ended	7
Problem-solving	14

The strongest negative response to the item would give a score of:

Student cohesiveness	42
Open-ended	42
Problem-solving	84

A shift towards a lower score would indicate a more positive response towards that model.

The initial 4-level questionnaire is shown on the following page. Development of the questionnaire using feedback from schools after the pilot field test is described below in section (ii) on questionnaire evaluation. For all tables and questionnaires the code key for pupil learning styles was: SC - student cohesiveness, OE - open endedness, PS1 - problem solving, RC - rule clarity, PS2 - problem solving check.

NAME SCHOOL CLASS

Remember that you are describing your actual classroom.

1. I get on well with other pupils in this laboratory class.	1 2 3 4
2. There is opportunity for me to pursue my own science interests in this laboratory class.	1 2 3 4
3. I read about everyday applications of science	1 2 3 4
4. My laboratory class has clear rules to guide my activities.	1 2 3 4
5. In my science class I find out how to relate my scientific knowledge to real life problems	1 2 3 4
6. I have little chance to get to know other pupils in this laboratory class.	1 2 3 4
7. In this laboratory class, I am required to design my own experiments to solve a given problem.	1 2 3 4
8. We are encouraged to suggest possible solutions to problems that we raise.	1 2 3 4
9. My laboratory class is rather informal and few rules are imposed on me.	1 2 3 4
10. I am required to find answers to problems put to us by the teacher.	1 2 3 4
11. Members of this laboratory class help me.	1 2 3 4
12. In my laboratory sessions, I can choose how to present my own results	1 2 3 4
13. We work in pupil teams to plan how to do the investigation.	1 2 3 4
14. I am required to follow certain rules in the laboratory.	1 2 3 4
15. We are encouraged to investigate problems related to our own interests.	1 2 3 4
16. I get to know students in this laboratory class well.	1 2 3 4
17. I am allowed to go beyond the regular laboratory exercise and do some experimenting of my own.	1 2 3 4
18. My teacher decides which investigations we do.	1 2 3 4
19. There is a recognized way for me to do things safely in this laboratory.	1 2 3 4
20. Teacher and pupils discuss together how to do the investigation.	1 2 3 4
21. I am able to depend on other students for help during laboratory classes.	1 2 3 4
22. In my laboratory sessions, I do different experiments from some of the other students.	1 2 3 4
23. We are told what equipment we are to use.	1 2 3 4
24. There are few fixed rules for me to follow in laboratory sessions.	1 2 3 4
25. We work in teams to plan the investigations.	1 2 3 4
26. It takes me a long time to get to know everybody by his/her first name in this laboratory class.	1 2 3 4
27. In my laboratory sessions, the teacher decides the best way for me to carry out the laboratory experiments.	1 2 3 4
28. Within our teams we are allowed to agree our individual tasks.	1 2 3 4
29. The teacher outlines safety precautions to me before my laboratory sessions commence.	1 2 3 4
30. We decide what our results mean.	1 2 3 4
31. I work cooperatively in laboratory sessions.	1 2 3 4
32. I decide the best way to proceed during laboratory experiments.	1 2 3 4
33. We are never given the opportunity to criticise the investigation.	1 2 3 4
34. My laboratory class is run under clearer rules than my other classes.	1 2 3 4
35. Our class discusses together whether the investigation has provided the answer to the problem.	1 2 3 4

For researcher's use Only: SC(PS) OE(FM) PS1 RC(TM) PS2

Designing the teacher questionnaire

The first stage in designing the teacher questionnaire was to compile a set of teaching styles, the differentiations of which could be measured and which would yield sufficiently different scores so that styles could be identified reliably. It was also important to ensure that this questionnaire was consistent with

(a) the pupil questionnaire developed by Fraser et al (7), and its derived form in this work;

(b) the literature, particularly on open-ended investigative practical work;

(c) styles highlighted in the non-statutory guidance which accompanied the National Curriculum Orders.

It was also essential to keep the length of the questionnaire to a minimum consistent with the recommendations of the EMSTAR group, yet be of sufficient detail and length to allow adequate reliability and validity. The historical review carried out at the start of this work indicated that stylistic development could be considered to fall largely into three domains: pre-Nuffield, Nuffield and post-Nuffield. These would be labelled traditional, flexible and problem-solving. In order to define these terms, it was necessary to identify the salient features of each style. This was done by studying some of the major influences which shaped the development of these styles. It is sufficient, for the purposes of this work, to confine such a study to the period beginning in 1960. This period was divided into the curriculum development era 1960-89 and the National Curriculum era. Key features of teaching styles were then identified as shown in the table on the following page.

Teaching style trends 1960-1989

Summary of some of the stylistic demands made on secondary science teachers by some teaching situations 1960-89 (i.e. up to the implementation of the first National Curriculum Orders.)

Teaching context	Knowledge of subject	Personality	Special skills
(a) Traditional	thorough, theoretical, mainly in one specialism	formal, disciplinarian	commanding presence
(b) Nuffield	thoroughly well integrated knowledge and understanding of theoretical and practical aspects.	open modes of thinking essential to develop enquiry methods.	disposed towards enquiry teaching methods
(c) mixed-ability classes	sound knowledge of subject and ability to express that knowledge in ways that pupils can understand	empathy towards pupils of different learning aptitude and background; particulary strong interest in children as individuals, preferably supported by a belief that this form of class organisation is *per se*, desirable.	intellectual flexibility to adjust readily to the widely different levels of cognitive ability
(d) integrated science	sound knowledge and awareness of some of the connections between science disciplines	lively interest in science as a whole	ability to convey enthusiasm outside own area of special interest
(e) social relevance of science	a knowledge of the social environmental, economic and technological aspects of science (a difficult aim in view of rather 'purist' approach which was used in most university science courses)	interest in the social side of science, and belief that this should be an integral aspect of science teaching	preferably first-hand experience of working in industrial or other jobs which apply science
(f) Less academically minded pupils	Sound knowledge with the ability to relate it to the level and experience of pupils	Convinced of the value of teaching science to these pupils	sympathetic to the needs of pupils as individuals

Innovative teaching styles in the 1990's
- the National Curriculum era

In June 1989, the Non-statutory Guidance for Science was published and stated in para,7:11:
"The National Curriculum for science, particularly AT 1: Exploration of Science, demands the development of an increasing independence in pupils, and responsibility for their own learning. Through a range of experiences, children should, eventually be able to:

- divide into groups where appropriate;
- decide upon objectives;
- carry out the task;
- collect data;
- analyse and interpret;
- evaluate and draw conclusions;
- communicate to others."

This requires a batch of teaching skills associated with pupil investigations, which are listed on p. A12 as:

- enabler
- manager
- presenter
- adviser
- observer
- challenger
- respondent
- evaluator.

These, when taken together with the literature and earlier discussion of practical problem solving, yields teaching skills which are associated with problem solving. The development of teaching styles in response to the major pressures for change in learning approaches from the 1960's to the present day (Nuffield exploration and the National Curriculum investigation) can be represented by 3 stylised approaches which form the basis for the 3 dimensions of the teacher questionnaire: traditional, flexible and problem-solving.

TRADITIONAL MODEL

1. Specialists in a single subject
2. Demonstrators of experiments
3. Rigid format for experimental writing
4. Teacher-led motivation
5. Discipline-centred
6. Uniform class approach
7. Exam-oriented teaching scheme
8. Statement-proving experiments
9. Little applied education theory
10. Scientific content confined to classroom
11. Little change in approach or method
12. Teacher directed

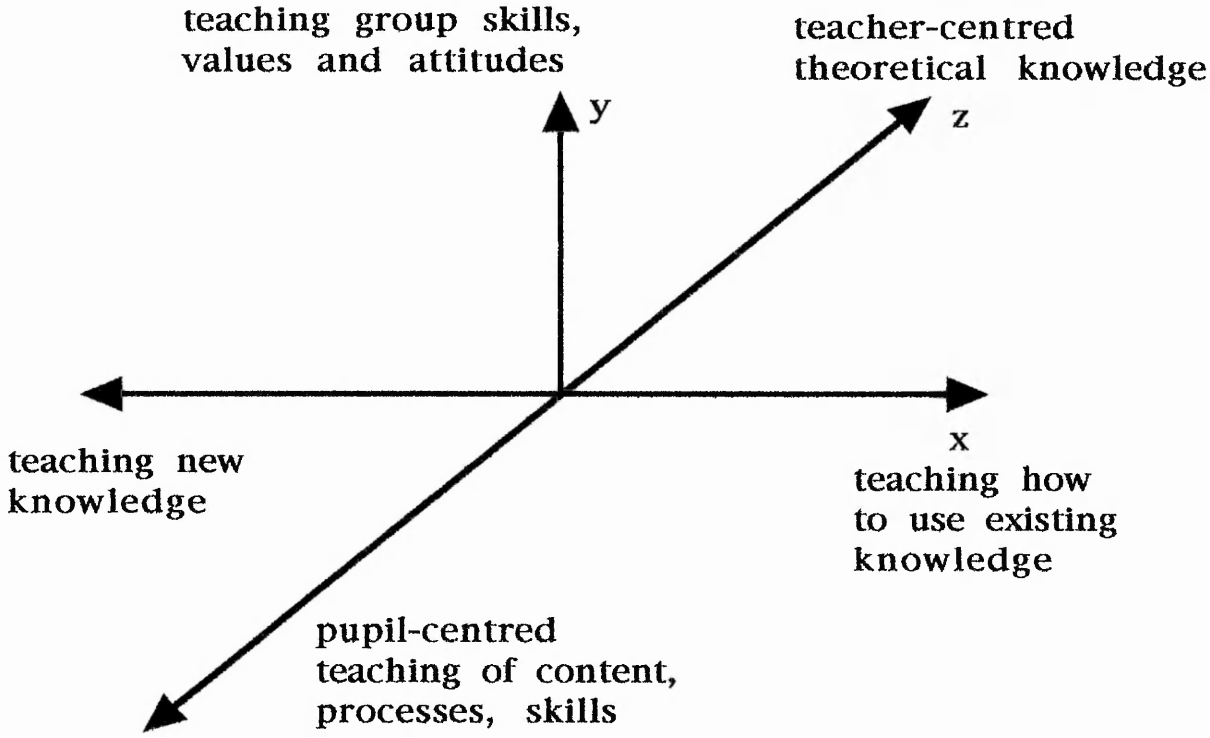
FLEXIBLE MODEL

1. Imaginative outlook
2. Academic flexibility
3. Variety of approaches used in lessons
4. Clear goals
5. Investigative approach
6. Exploration
7. Creative, flexible
8. Able to cope with the unfamiliar
9. Problem solving situations
10. Innovative
11. Preference for academic challenges
12. Child-centred

PROBLEM-SOLVING MODEL

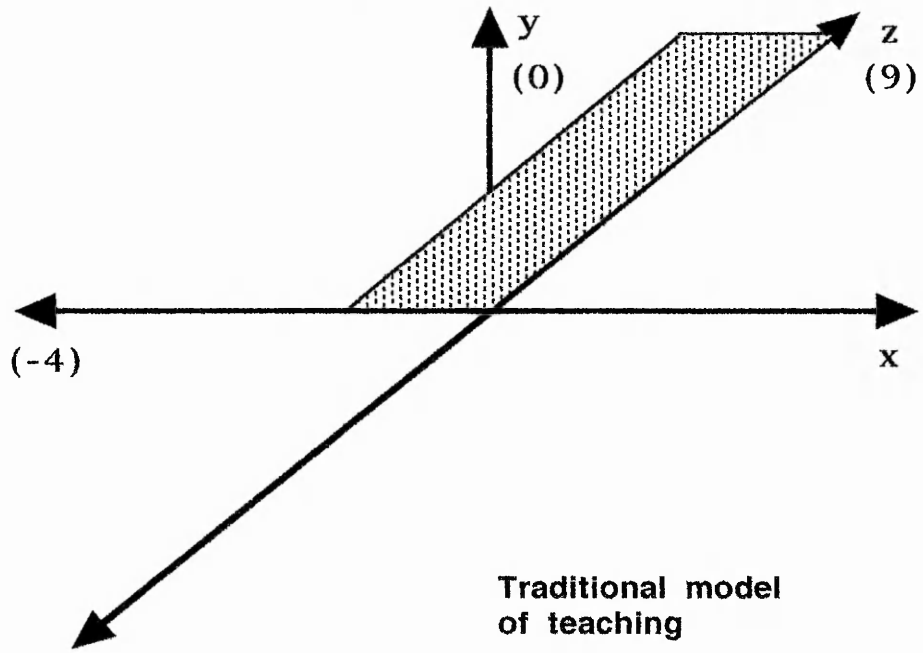
1. Multi-disciplinary approach to teaching
2. Emphasises social implications of science
3. Adopts co-operative approach to learning
4. Uses wide variety of approaches to practical work
5. Observations recorded in a variety of styles
6. Pupils encouraged to draw own conclusions
7. Frequent use of audio-visual aids
8. Intrinsic pupil motivation through relevance to pupil experience
9. Various methods of practical assessment used
10. Use knowledge to solve real-world problems
11. Knowledge related to everyday applications
12. Encourages pupil learning in all science disciplines.

A comparison of three typical teaching styles used as the basis for the design of the questionnaire research instrument.
In order to relate these styles to the model used for techno-science practical investigations, it was necessary to map the styles The taxonomy of problem solving used by Nott, as described previously in this thesis in the section on problem solving, was adapted by the present author to cover teaching styles as shown below.

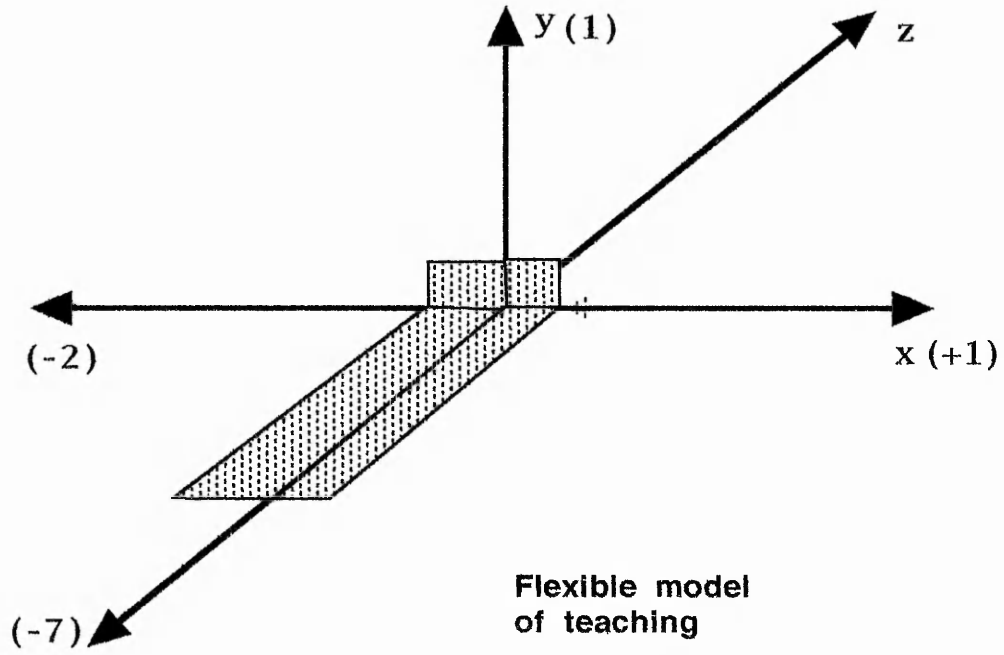


Using this set of axes, the three models of teaching style can be represented by shaded areas which are proportional to the relative weighting accorded to the dimensions labelled on the axes. This can be done by assigning a value of one unit (positive or negative) to each of the characteristics listed for each of the styles. For example, demonstrating an experiment would earn a score of +1 on the z-axis, whereas child-centred investigation would earn -1 on the same axis. This approach could enable each of the styles to be described in terms of criteria and then represented graphically.
These criteria yielded the scores:
Traditional model:- $x = -4, y = 0; z = 9.$
Flexible model $x = -2, +1, y = 1; z = -7.$
Problem solving model $x = -1, +1, y = 3; z = -8.$

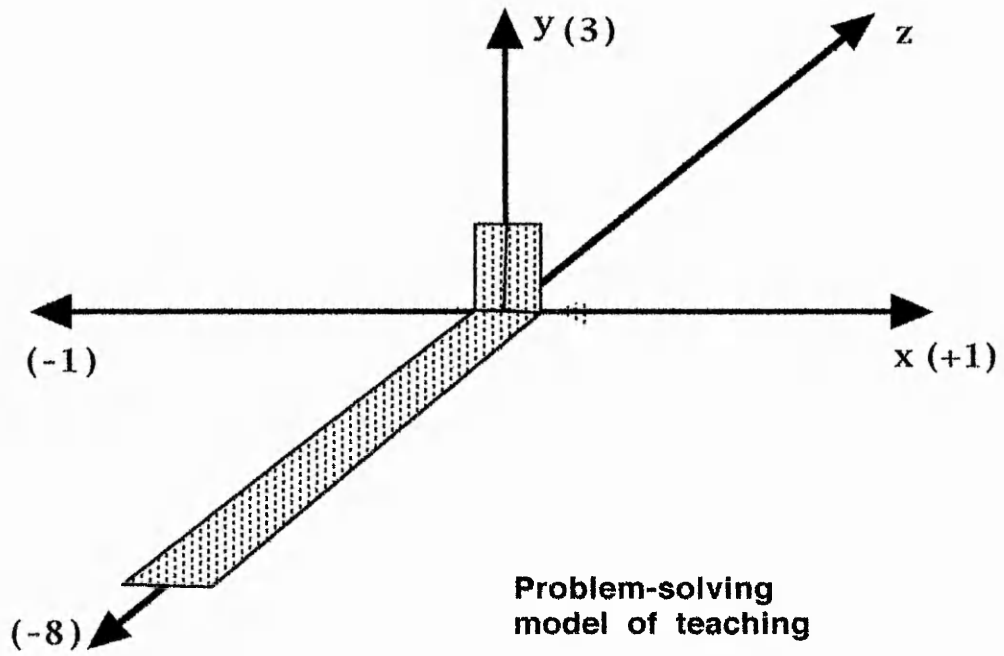
Approaching the models in this simple manner produces maps as shown in the following three diagrams:



Traditional model of teaching



Flexible model of teaching



Problem-solving model of teaching

Finally the three dimensions were mapped on to the questionnaire as shown below.

QUESTION NUMBER	TRADITIONAL MODEL
2	1.Specialists in a single scheme
5	2. Demonstrators of experiments
8	3. Rigid format for experimental writing
29	4. Teacher-led motivation
11	5. Discipline-centred
14	6. Uniform class approach
17	7. Exam-oriented teaching scheme
20	8. Statement-proving experiments
23	9. Little applied education theory
26	10. Scientific content confined to classroom
32	11. Little change in approach or method
35	12. Teacher directed

QUESTION NUMBER	FLEXIBLE MODEL
1	1. Imaginative outlook
4	2. Academic flexibility
7	3. Variety of approaches used in lessons
10	4. Clear goals
13	5. Investigative approach
16	6. Encourages exploration
19	7. Creative, flexible
22	8. Able to cope with the unfamiliar
25	9. Problem solving situations
28	10. Innovative
31	11. Preference for academic challenges
34	12. Child-centred

QUESTION NUMBER	PROBLEM-SOLVING MODEL
6	1. Multi-disciplinary approach to teaching
9	2. Emphasises social implications of science
36	3. Adopts co-operative approach to learning
12	4. Uses wide variety of approaches to practical work
15	5. Encourages pupils to record experimental work in a variety of ways
18	6. Pupils encouraged to draw own conclusions from own data
21	7. Frequent use of audio-visual aids
33	8. Intrinsic pupil motivation through relevance to pupil experience
27	9. Various methods of practical assessment used
3	10. Emphasises using knowledge to solve real-world problems
24	11. Knowledge set in the context of its everyday applications
30	12. Encourages pupil learning in all science disciplines.

Following the style of the questionnaires used by Fraser et al, the initial trial questionnaire had a 4-level response scale and is shown on the following page. The development of the final version is described below in the section on questionnaire evaluation.

TEACHER NAME/CODE.....SCHOOL.....DATE.....

*Remember that you are describing your **actual** classroom practice*

1. I welcome opportunites to try out imaginative approaches 1 2 3 4
2. I prefer to teach entirely within my own specialism 1 2 3 4
3. I often ask pupils to read about everyday applications of science 1 2 3 4
4. I welcome opportunites to choose my own approaches to teaching 1 2 3 4
5. I prefer to demonstrate most experiments to show pupils what to do. 1 2 3 4
6. I look for links with other science disciplines in my teaching. 1 2 3 4

7. In my science class I often try novel ideas if time permits 1 2 3 4
8. My pupils use a standard format for writing up experiments 1 2 3 4
9. I discuss with pupils how to relate their scientific knowledge to social and technological implications 1 2 3 4
10. I set clear goals for the pupils to follow but allow pupils some freedom 1 2 3 4
11. I require pupils to do as they are told and follow my rules in the lab. 1 2 3 4
12. In different lessons I use different approaches with pupils. 1 2 3 4

13. My pupils usually plan by themselves how to do the set investigation 1 2 3 4
14. Pupils usually carry out the same experiment as per given instructions 1 2 3 4
15. I often allow pupils to record their results in a variety of different ways 1 2 3 4
16. A variety of explorations should precede understanding of a given concept. 1 2 3 4
17. I base my scheme of work on the requirements of external examinations 1 2 3 4
18 Pupils are often required to look for information from a variety of sources. 1 2 3 4
19 I enjoy doing slightly risky things to test my own novel ideas. 1 2 3 4
20 Pupils themselves plan:- investigate own problems & test own hypotheses 1 2 3 4
21 I find frequent use of audio-visuals aids is timewasting and unnecessary 1 2 3 4
22 I am inclined to be anxious when faced with unfamiliar situations 1 2 3 4
23 The findings of educational research have little relevance to schools 1 2 3 4
24 All lessons should be presented in a context of everyday applications 1 2 3 4

25 I encourage pupils to find answers to problems which I put to them. 1 2 3 4
26 Science is learnt best by classroom-based rather than extra-mural activites 1 2 3 4
27 The only reliable method of assessing pupils is by written tests 1 2 3 4
28 I enjoy curriculum development and trying out new teaching schemes 1 2 3 4
29. I decide the class activities and motivate the pupils to keep them on task. 1 2 3 4
30. I plan lesson content to show pupils the links between different sciences 1 2 3 4

31. Science courses should provide challenging material for bright pupils 1 2 3 4
32 I prefer not to change lesson plans which have been successful 1 2 3 4
33. I usually motivate my pupils by relating science to pupils' own interests 1 2 3 4
34. I encourage pupils to try ideas beyond the set laboratory exercise 1 2 3 4
35. Pupils progress best when given clear directions for the experiments 1 2 3 4
36. I encourage pupils to work co-operatively in laboratory sessions. 1 2 3 4

For researcher's use Only: TM FM PS

Method used for analysing questionnaire response scoring

As with the pupil questionnaire, the response instructions indicated choosing '1' for the strongest agreement and '6' for the strongest disagreement. Some of the questions were stated negatively so the score pattern was reversed. The lower the score for each of the three models, the more strongly the teacher fits that model. The scoring procedure was:

(i) A circled 1 is given a score of 1, a circled 6 is given a score of 6.

(ii) When a question is asked in the negative form the reverse score is recorded.

(iii) Omitted or incorrectly answered questions are given a score of 3.5.

The strongest positive response to the item would then give a score of:

Traditional Model	12
Flexible Model	12
Problem Solving Model	12

The strongest negative response to the item would give a score of:

Traditional Model	72
Flexible Model	72
Problem Solving Model	72

A shift towards a lower score would indicate a more positive response towards that model.

Illustrative examples of converting score to teaching style

(i) Teacher questionnaire

Questions in bold type were stated as opposites and the scores were reversed.

TRADITIONAL MODEL

This was evaluated with questions 2, 5, 8, 11, 14, 17, **20**, 23, 26, 29, 32, 35.

FLEXIBLE MODEL

This was evaluated using questions 1, 4, 7, 10, 13, 16, 19, **22**, 25, 28, 31, 34.

PROBLEM-SOLVING MODEL

This was evaluated using questions 3, 6, 9, 12, 15, 18, **21**, 24, **27**, 30, 33, 36.

To illustrate typical scores on questionnaires received from teachers, two examples are given below.

EXAMPLE 1 (using first draft of questionnaire on initial trial)
Teacher (A) scored 28 on the traditional model, and 16 on both flexible and problem-solving models. This teacher was known to be strongly in favour of innovation and problem-solving, and had a firm approach to class discipline.

EXAMPLE 2 (using first draft of questionnaire on initial trial)
Teacher (B), older than (A) and also with a firm approach to class discipline but active in curriculum development, also scored 28 on the traditional model, 22 on the flexible model and 25 on the problem-solving model.

Having completed the questionnaire design, the work progressed to the next stage - evaluation.

(ii) Questionnaire evaluation

Pilot study

This occurred in mid-1992
(a) One local school was selected to reduce delays in obtaining feedback, and also it was one of the schools selected for a case study (study 2). All teaching staff completed a questionnaire.
(b) The questionnaire responses were analysed and the resulting profiles were discussed with the staff. This produced changes to both questionnaires.

Full-scale field test

(a) Having refined the draft questionnaire in the light of feedback from staff and pupils, an invitation was sent to all EMSTAR members and the first full field test occurred in December 1992. It continued in follow-up runs until 1994.

(b) School A (an 11-18 mixed comprehensive) and school B (an 11-18 school for girls only) offered to participate in intervention projects and are discussed as full case studies.

(c) A good response was achieved from EMSTAR members and around 1000 questionnaires were completed over a period of two years.

Outcomes of field tests

Pilot study

The feedback from respondents indicated that there was insufficient scope for differentiation and that some re-phrasing was necessary.

(i) The degree of fine discrimination allowed by the 4-level choice response was considered by some of the teachers to be insufficient to reveal small shifts over a period of one year. In terms of instruments in experimental science, one would say the instrument had insufficient resolution to distinguish fine details. Based on feedback from EMSTAR members and from the pilot test, it was decided to increase the number of possible responses to 6. A second draft of the questionnaire was produced and used in the full-scale field test. The same change was made to the pupil questionnaire and the final versions are shown on the following four pages.

(ii) It was thought that some of the phrases on the pupil sheet such as "laboratory class" and "laboratory sessions" might sound a little strange to pupils.

(iii) Some teachers observed that it had not been possible to respond in the "1" column as the statements implied a continuous use of that particular approach, whereas in practice this would not occur. Examples quoted most frequently were questions 13, 16, 29, 30 and 35.

THE NOTTINGHAM TRENT UNIVERSITY

SCHOOL SCIENCE SURVEY

Directions

This questionnaire contains statements about practices which take place in **your** science class. You will be asked how strongly **you** agree with each statement.

There are no 'right' or 'wrong' answers. Your opinion is what we welcome.

Think about how well each statement describes what this science class is actually like for you.

Draw a circle around the number which best fits what you think.

If you agree strongly, circle 1.

If you disagree strongly, circle 6 and so on.

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

Practice Example.

Suppose that you were given the statement:

"I work co-operatively in science laboratory sessions".

You would need to decide whether you thought that you actually work well with other people when you are doing experiments. If you agree that this happens most of the time, you would circle the number1 on your Answer Sheet.

If you feel it doesn't happen at all, circle 6 and so on.

Please remember to write your name and other details at the top of the reverse side of this page.

Thank you very much for your help with this questionnaire.

THE NOTTINGHAM TRENT UNIVERSITY

SCHOOL SCIENCE SURVEY

NAME .....SCHOOL..... CLASS .....DATE.....

*Remember that you are describing your **actual** class experience.*

1. I get on well with other pupils in this class.	1 2 3 4 5 6
2. There is rarely opportunity for me to pursue my own science interests in science lessons.	1 2 3 4 5 6
3. I read about everyday applications of science.	1 2 3 4 5 6
4. We are given clear rules to guide our activities.	1 2 3 4 5 6
5. In science, I find out how to relate my scientific knowledge to real life problems	1 2 3 4 5 6
6. I have little chance to get to know other pupils in this laboratory class.	1 2 3 4 5 6
7. In this laboratory class, I am required to design my own experiments to solve a given problem.	1 2 3 4 5 6
8. We are encouraged to suggest possible solutions to problems that we raise.	1 2 3 4 5 6
9. My class is rather informal and few rules are imposed on me.	1 2 3 4 5 6
10. I am required to find answers to problems put to us by the teacher.	1 2 3 4 5 6
11. Other pupils in the class help me.	1 2 3 4 5 6
12. In science experiments, I can choose how to present my own results	1 2 3 4 5 6
13. We work in groups to plan how to do the investigation set by the teacher.	1 2 3 4 5 6
14. I am required to follow certain rules in the laboratory.	1 2 3 4 5 6
15. We are encouraged to investigate problems related to our own interests.	1 2 3 4 5 6
16. I get to know other pupils in this class well.	1 2 3 4 5 6
17. I am allowed to go beyond the regular laboratory exercise and do some experimenting of my own.	1 2 3 4 5 6
18. My teacher decides which investigations we do.	1 2 3 4 5 6
19. There is a recognized way for me to do things safely in this laboratory.	1 2 3 4 5 6
20. Teacher and pupils discuss together how to do the investigation.	1 2 3 4 5 6
21. I am able to depend on other pupils for help during lessons.	1 2 3 4 5 6
22. In my science lessons, I do different experiments from some of the other pupils.	1 2 3 4 5 6
23. We are told what equipment we are to use.	1 2 3 4 5 6
24. There are few fixed rules for me to follow in science lessons.	1 2 3 4 5 6
25. We work in teams to plan our own investigations.	1 2 3 4 5 6
26. It takes me a long time to get to know everybody by his/her first name in this class.	1 2 3 4 5 6
27. In my laboratory sessions, the teacher decides the best way for me to carry out the laboratory experiments.	1 2 3 4 5 6
28. Within our teams we are allowed to agree our individual tasks.	1 2 3 4 5 6
29. The teacher outlines safety precautions to us before we begin each experiment.	1 2 3 4 5 6
30. We decide what our results mean.	1 2 3 4 5 6
31. I work cooperatively in science lessons.	1 2 3 4 5 6
32. I decide the best way to proceed during laboratory experiments.	1 2 3 4 5 6
33. We are never given the opportunity to criticise the investigation.	1 2 3 4 5 6
34. My science lessons are run under clearer rules than my other classes.	1 2 3 4 5 6
35. Our class discusses together whether the investigation has provided the answer to the problem.	1 2 3 4 5 6

For researcher's use Only: SC(PS) OE(FM) PS1 RC(TM) PS2

THE NOTTINGHAM TRENT UNIVERSITY

SCIENCE TEACHING STYLES SURVEY

Introduction

I believe that all too often education changes are introduced without testing their worth in the classroom. Furthermore, good ideas are often lost or go unrecognised for lack of evaluation and dissemination. As your science department is actively involved in introducing new approaches to pupil investigations, I would value your support in completing this questionnaire.

Directions

This questionnaire contains statements about practices which could take place in school science classes. You will be asked to rate how strongly you agree or disagree with statements in terms of **your usual practice.**

There are no 'right' or 'wrong' answers. Your opinion is what is welcomed.

Please think about how well each statement describes your **actual** science teaching. Draw a circle around the number which best fits what you think.

If you agree strongly, circle 1.

If you disagree strongly, circle 6 etc.

Please be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

I hope that you will feel comfortable about writing your name at the top of the reverse side of this page to enable me to give you some feedback.

Thank you very much for your participation.

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SCHOOL SCIENCE SURVEY

TEACHER NAME/ CODE .....SCHOOL.....DATE.....

*Remember that you are describing your **actual** classroom practice*

1. I welcome opportunites to try out imaginative approaches	1 2 3 4 5 6
2. I prefer to teach entirely within my own specialism	1 2 3 4 5 6
3. I often ask pupils to read about everyday applications of science	1 2 3 4 5 6
4. I welcome opportunites to choose my own approaches to teaching	1 2 3 4 5 6
5. I prefer to demonstrate most experiments to show pupils what to do.	1 2 3 4 5 6
6. I look for links with other science disciplines in my teaching.	1 2 3 4 5 6
7. In my science class I often try novel ideas	1 2 3 4 5 6
8. My pupils use a standard format for writing up experiments	1 2 3 4 5 6
9. I discuss with pupils how to relate their scientific knowledge to social implications	1 2 3 4 5 6
10. I set clear goals for the pupils to follow but allow pupils some freedom	1 2 3 4 5 6
11. I require pupils to do as they are told and follow my rules in the lab.	1 2 3 4 5 6
12. In different lessons I use different approaches with pupils.	1 2 3 4 5 6
13. My pupils usually plan how to do the set investigation	1 2 3 4 5 6
14. Pupils usually carry out the same experiment as per given instructions	1 2 3 4 5 6
15, I often allow pupils to record their results in a variety of different ways	1 2 3 4 5 6
16. Pupils frequently carry out a variety of explorations leading to the understanding of a given concept.	1 2 3 4 5 6
17. I base my scheme of work on the requirements of external examinations	1 2 3 4 5 6
18 Pupils are often required to look for information from a variety of sources.	1 2 3 4 5 6
19 I enjoy doing slightly risky things to test my own novel ideas.	1 2 3 4 5 6
20 Pupils themselves plan:- investigate own problems & test own hypotheses	1 2 3 4 5 6
21 I find frequent use of audio-visuals aids is timewasting and unnecessary	1 2 3 4 5 6
22 I am inclined to be anxious when faced with unfamiliar situations	1 2 3 4 5 6
23 The findings of educational research have little relevance to schools	1 2 3 4 5 6
24 All lessons should be presented in a context of everyday applications	1 2 3 4 5 6
25 I encourage pupils to find answers to problems which I put to them.	1 2 3 4 5 6
26 Science is learnt best by classroom-based rather than extra-mural activites	1 2 3 4 5 6
27 The only reliable method of assessing pupils is by written tests	1 2 3 4 5 6
28 I enjoy curriculum development and trying out new teaching schemes	1 2 3 4 5 6
29. I decide the class activities and motivate the pupils to keep them on task.	1 2 3 4 5 6
30. I plan lesson content to show pupils the links between different sciences	1 2 3 4 5 6
31. Science should provide intellectually challenging material for bright pupils	1 2 3 4 5 6
32 I prefer not to change lesson plans which have worked well	1 2 3 4 5 6
33. I usually motivate my pupils by relating science to pupils' own interests	1 2 3 4 5 6
34. I encourage pupils to try ideas beyond the set laboratory exercise	1 2 3 4 5 6
35. Pupils progress best when given clear directions for the experiments	1 2 3 4 5 6
36. I encourage pupils to work cooperatively in laboratory sessions.	1 2 3 4 5 6

For researcher's use Only: TM FM PS

Full-scale field test

The results from four major respondees are discussed below and a further two are reported in full as case studies. Not all school responses were included as some provided sample sizes which were rather too small to be useful in this study e.g. from two special schools, a primary school and a college of further education.

To assist clarity of presentation, the results from each school are presented in the following pages as a one-page summary, followed by a commentary. The commentary focusses on the central issue of whether the questionnaires provided a reliable instrument to be used to evaluate the central hypothesis of this work.

The two questions to be answered were,
(i) "Can teaching and learning styles be measured with sufficient accuracy to enable the effects of intervention research to be demonstrated?"
(ii) "Are the measurements derived from each questionnaire element equally reliable?"

Results from the schools are summarised in tabular form on the following pages and wider issues arising from the results are discussed in chapter 10.

Comparison of teaching and learning styles at school 1

a) Learning styles

School		Date of survey			
1		Autumn 1992			
YEAR 10					
	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
10H	19.18/5.12	30.62/4.41	29.50/3.03	15.56/7.99	23.5/6.36
10L	18.34/3.73	27.70/5.89	27.76/3.35	17.72/4.25	24.16/3.47
10J2	16.34/6.26	28.85/5.45	27.46/3.72	18.79/5.94	21.63/5.71
10W	20.15/6.12	26.57/4.96	27.39/5.06	18.15/6.10	25.44/5.20
mean total	18.5	27.93	27.97	17.8	23.68
SD of totals	1.4	1.6	0.88	0.81	1.37
mean SD	5.31	5.18	3.79	6.07	5.19
rank order of style preferences			**TM, SC, PS2, OE(FM), PS1**		
YEAR 11					
	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
11FD	14.91/5.85	24.89/5.03	25.00/3.41	16.93/5.76	21.67/3.30
rank order of style preferences			**SC, TM, PS2, OE (FM), PS1**		

b) Teaching styles

School		Date of survey			
1		Autumn 1992			
TEACHERS	category of teaching style				
	TM	FM	PS		
teacher	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.		
1	24/1.41	42/1.80	44/1.31		
2	43/0.86	31/1.04	27/0.83		
3	29/1.32	44/1.49	37/1.19		
4	32.5/1.27	29/0.86	34.50/1.26		
mean total	32.12	36.5	35.62		
SD of totals	6.96	6.57	6.07		
mean SD	1.33	1.30	1.15		
rank order of styles		**TM, FM, PS**			

Commentary on results

The low values of pupil standard deviations for each total score e.g. 1.4 for year 10 SC, indicate a high degree of homogeneity within each style. This would be expected when classes are taught by a variety of staff in a mixed-ability system and so are exposed to similar learning environments. The low values of SD's for teachers for all styles indicate a greater accuracy of self-perception, which would be expected. The pupils in year 10 of this survey were in year 7 in 1989 when the Science Orders for the National Curriculum came into force, so being the first cohort to follow the new curriculum, whereas year 11 were the last group to follow the old system. Thus the results for years 10 and 11 provide a possible guide to the effect of this change on learning styles in the short term, within the limitations of this questionnaire. Comparing the rank orders for years 10 and 11 shows the same order, but social cohesiveness and traditional learning are interchanged. This is significant in terms of establishing the usefulness of the questionnaire as a tool for measuring trends as we would not expect much change in learning styles from one year group to the next in the same school and taught by the same teachers. The altered position of student cohesiveness is not particularly significant for this study because student cohesiveness is a social aspect of the class environment and may well not correlate with specific learning styles (this issue was explored in the case studies) so the pattern in learning styles for all pupils in years 10 and 11 is that the traditional style is more common than problem solving, with open ended least common (but statistically inseparable from PS1).

We may also compare teaching and learning styles taking the overall results of all pupils and teachers. Combining the totals for years 10 and 11 revealed:

ALL PUPILS	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Year	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
10	18.50	27.93	27.97	17.80	23.68
11	14.91	24.89	25.00	16.93	21.67
mean total	33.41	52.82	52.97	34.73	43.35
mean SD	5.58	5.11	3.60	5.93	4.25
rank order of style preferences			SC, TM, PS2, OE, PS1		

A comparison with teaching styles indicates the same top ranking for the traditional method with mean scores for problem solving and open ended being within one standard deviation of each other. This further strengthens the earlier indication of questionnaire reliability but was evaluated in more detail in case study 1.

Comparison of teaching and learning styles at school 2

A) Learning styles					
School 2			Date of survey		
			Autumn 1992		
YEAR 10					
	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
10QLK	19.0/5.42	25.84/3.78	24.86/2.78	16.0/4.21	19.15/6.17
10QLTD	14.56/2.61	22.78/3.63	23.12/3.52	18.9/3.7	17.78/4.16
10YQD	16.86/5.49	26.76/6.26	25.80/4.57	15.9/5.29	21.06/5.80
10DLYH	18.33/6.48	27.38/2.50	26.88/3.46	18.88/2.89	22.88/5.20
10QEH	20.19/5.98	29.90/4.77	27.00/4.34	21.38/5.17	24.80/6.14
10YVT	17.12/5.25	27.62/5.11	26.79/2.60	18.54/3.72	21.70/6.39
mean total	17.68	26.71	25.74	18.26	21.22
SD of totals	1.78	2.14	1.39	1.88	2.3
mean of SD's	5.21	4.34	3.55	4.16	5.64
rank order of style preferences			SC, TM, PS2, PS1, OE		
YEAR 11					
	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
11DEH	14.27/2.52	24.77/3.52	25.25/4.01	17.70/4.06	21.09/4.22
11THY	17.39/6.07	23.13/3.32	24.69/3.69	17.08/4.77	21.10/5.51
mean total	15.83	23.95	24.97	17.39	21.04
SD of totals	1.56	0.82	0.28	0.31	4.5
mean of SD's	4.30	3.42	3.85	4.42	4.87
rank order of style preferences			SC, TM, PS2, OE, PS1		
B) Teaching styles					
TEACHERS	category of teaching style				
	TM	FM	PS		
teacher	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.		
1	42/1.71	27/1.92	32/1.31		
2	36/1.00	32.5/1.88	31/1.04		
3	32.5/1.25	33.5/1.57	30/1.24		
4	31.5/1.57	41/1.50	40/1.60		
5	39/1.01	36.5/1.16	36/0.71		
mean total	36.2	34.1	32.25		
SD of means	1.32	1.21	1.18		
mean of SD's	1.31	1.61	1.17		
rank order of styles		PS, FM,TM			

Commentary on results

Comparing the rank orders for years 10 and 11 shows the same styles in the top three, but a shift from open-ended (Nuffield) style to problem solving at the lower end. Such a trend would be expected from our definition of the problem-solving learning style in terms of the specification for investigative practical work in the National Curriculum. This increases our confidence in the reliability of the questionnaire as a tool for evaluating trends. This issue is of vital importance in testing the central hypothesis of this work and was therefore explored further in the second case study.

A further point on interest was the comparison of teaching and learning styles taking the overall results of all pupils and teachers. Combining the totals for years 10 and 11 showed that

ALL PUPILS	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Year	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
10	17.68	26.71	25.74	18.26	21.22
11	15.83	23.95	24.97	17.39	21.04
mean total	33.51	50.66	50.71	35.65	42.26
mean SD of totals	1.67	1.48	0.84	1.10	3.40
rank order of style preferences			SC, TM, PS2, PS1, OE/FM		

The category SC (student cohesiveness) is a social aspect of the class environment and may well not correlate with specific learning styles (this issue was explored in the case studies) so the pattern in learning styles for all pupils in years 10 and 11 is that the traditional style is more common than problem solving, with open ended least common (but once again statistically inseparable from PS1).

A comparison with teaching styles shows a surprising reversal of the order. This weakens the earlier indication of questionnaire reliability and adds weight to the need for questions to be evaluated in more detail. In particular, it would appear from the comparatively large standard deviation of PS2 that this category presented a detrimental effect on the overall reliability. Therefore a more detailed evaluation of question categories was carried out in case study 1.

Comparison of teaching and learning styles at schools 3 and 4

These schools were selected as the first is a selective grammar school for girls and the second was originally a selective grammar school for boys, and at the time of the survey (prior to its re-organisation) retained much of its original character and was still single-sex.

School 3

Date of survey - Autumn 1992

TEACHERS	category of teaching style				
	TM	FM	PS		
teacher					
1	53	18	26		
rank order of styles		**FM,PS,TM**			
PUPILS TAUGHT BY TEACHER 1					
	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
10K	14.9/0.88	28.2/1.24	25.3/1.65	16.5/0.99	18.5/1.30
rank order of styles			**SC, TM, PS2, PS1, FM**		

The reversal of styles is consistent with the findings of school 2, but inconsistent with school 1. Although the sample size in this school is small, this finding was further studied in the case studies and supported our decision not to use the questionnaire as a means of providing absolute data, but rather indicating trends based on differences in mean and total scores.

School 4

	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
Class	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.	TOTAL/S.D.
YEAR 10					
10.1	15.94/5.50	27.29/4.02	24.38/2.89	14.64/3.41	19.41/4.90
10JS	18.00/4.81	25.97/4.39	26.33/4.50	16.77/3.95	19.63/4.70
10CL	22.37/4.76	26.62/5.12	25.91/3.09	21.20/4.73	22.45/6.63
10JV	20.37/4.70	28.08/2.72	25.83/2.33	21.37/3.10	21.45/6.87
mean total	19.17	26.99	25.61	18.45	20.73
mean of SD's	4.94	4.06	3.53	3.79	5.78
rank order	2	5	4	1	3

This was a most interesting result, which apparently indicated that pupils in both these traditional selective single-sex schools appeared to report a learning environment where the traditional approach dominated modern learning methods. This would be the expected outcome for such a survey and added weight to the degree of validity of the questionnaire as a whole. However, without a full evaluation of the reliability of each of the questions (which would be beyond the scope of this work, although a partial evaluation is undertaken in the first case study) it was not possible to comment on the significance of this result.

This chapter has dealt with aim 4 of this work and the results of the case studies may now be discussed in the chapters 8 and 9.

Chapter 8
CASE STUDY 1

CONTENTS

CASE STUDY 1

This case study was intended to fulfil the first part of aim 5, which was:
To carry out field tests which:
(i) investigate whether 'techno-science' provides a successful approach for involving pupils in educational activities which span the science-technology continuum, and extend to cross-curricular activities such as work experience schemes.
This material was put together principally during the 1991/1992 and 1992/1993 academic years, with a follow-up in 1995. The institutions involved were the science department of a single-sex school, The Nottingham Trent University and Hickings Dyeing contractors of Nottingham.

The benefits initially predicted for this three way link were to:-
(i) allow the school to have a short scheme of work which would go some way towards addressing cross curricular theme in the National Curriculum, particularly Economic and Industrial Understanding;

(ii) enable University students to have experience of a link project involving pre-sixteen education and an industrial firm and

(iii) provide insight into how real-life scientific problem solving can be related to work within a classroom.

Objectives of the link

This case study was used to explore two aspects of the overall hypothesis of this work:
Firstly, the time pressure on the school curriculum is such that innovations in providing enriched experiences for pupils can be introduced only at the expense of other forms of learning. For example, in this case study, learning science experientially through visiting external industrial sites at which applications of science were evident, could be provided by removing the opportunity for pupils to engage in the normal school work experience programme. Therefore an important aspect of this study was to carry out a comparative evaluation of these two forms of pupil experience.
Secondly, it was predicted that, assuming the correctness of the 'techno-science' paradigm, and that such a paradigm is best approached in its natural setting where science theory can be seen by pupils at first hand to be

directly linked to technological applications in the 'real world', pupils given this 'techno-science' investigation opportunity should achieve more than their peers who followed the usual separate subject approach. There should be a clear differential in value added. Associated with the different learning approach there should be differences in teaching styles so that the interaction of learning with the project approach and teaching style should show measurable trends.

This led to two objectives for the study:

(i) to compare the school's usual method of delivering work experience for year 10 pupils, with the method of specialised work experience obtained through extended science investigations in the context of the 1991 Orders for Science in the National Curriculum.

(ii) to evaluate pupils' progress and perceptions on these two pathways.

A further aspect of this objective, that of exploring the two-way effects of the learning project on styles, attitudes and perceptions of teachers, had to be partially abandoned due to difficulties associated with school re-organisation, but was evaluated more thoroughly in the second case study. Nevertheless, even with the limited observations available, some useful information was extracted and is described below.

The company: Hickings Fabric Dyers, Nottingham.
Nature of business: suppliers of dyed fabrics.
Hickings bleach, dye and finish fabrics which are then returned to the company for cutting and assembling.
The main customers are mail order catalogue companies.
78% of the annual turnover is spent on energy. Heating process requirements - using gas, oil, electricity and steam heating - total 1 megawatt costing £429,000 per annum. Hickings Fabric Dyers is a medium sized factory. It employs over 180 people. Most of these employees live in the Nottingham area to facilitate travelling to and from work.

The school

Originally a grammar school for girls, it became a girls comprehensive and was, at the time of this work, amalgamating with a nearby boys school to form an 11-18 comprehensive school. The science department entered pupils for three different GCSE courses, but selected pupils following the Nuffield Co-ordinated Science course as being most appropriate. The GCSE results for the second year of the link are summarised below.

MEG 18.08.94 GCSE SUMMER 1994

NUFFIELD CO-ORDINATED SCIENCE DOUBLE AWARD
FIRST GRADE

Grade	Number of pupils	% of pupils
A*	0	0
A	1	2.6
B	2	5.1
C	1	2.6
D	9	23.1
E	13	33.3
F	11	28.2
G	0	0
U	2	5.1
NO RESULT	5	
TOTAL 44		
SECOND GRADE		
A*	0	
A	1	2.6
B	2	5.1
C	1	2.6
D	9	23.1
E	13	33.3
F	11	28.2
G	0	0
U	2	
NO RESULT	5	
TOTAL 44		

The pupils involved

All the pupils involved with this project, both those in year 10 during 1991/1992 and those during 1992/1993, were of just above average academic achievement relative to their cohort. This is illustrated in the latter case by their GCSE examination results shown below. The pupils who participated in the link are shown in bold type. It was hoped to demonstrate that these pupils gained more from the link that the remainder of the cohort who followed the normal work experience route and who would form the control group.

However, due to the problems of re-organisation, only one pupil (candidate no. 1081) who had participated in the project could be traced through to year 12. The results are displayed below.

MIDLAND EXAMINING GROUP - 18/08/94 CENTRE 28118

MANSFIELD QU. ELIZABETH'S NUFFIELD CO-ORD SCIENCES D/AWARD

Candidate number	Grade
1004	F/F
1008	F/F
1010	E/E
1013	E/E
1014	F/F
1016	E/E
1018	F/F
1021	F/F
1028	D/D
1029	X/X
1031	E/E
1034	F/F
1035	D/D
1039	D/D
1045	E/E
1051	X/X
1052	E/E
1054	E/E
1055	F/F
1062	B/B
1067	**C/C**
1072	**X/X**
1081 pupil on project and traced to yr.12	**B/B**
1082	E/E
1083	D/D
1084	E/E
1085	D/D
1086	F/F
1088	D/D
1097	D/D
1099	E/E
1104	**D/D**
1107	U/U
1109	U/U
1111	X/X
1120	F/F
1128	**F/F**
1131	F/F
1132	D/D
1135	X/X
1137	A/A
1138	E/E
1139	E/E
1140	E/E

An outline of the link

During the first year of this school-industry link (academic year 1991/1992) six year 10 pupils from the QE Girls' school were questioned about their work experiences at various establishments. They were also asked to visit the Hickings factory and to produce a booklet showing the processes involved. This was all incorporated within a year 10/11 project which would give the girls some understanding of industrial problem solving.

In the second year of the link (1992-3), four year 10 pupils volunteered to be removed from the school's work experience week and placed into a specifically scientific school-industry project which would provide experience of investigative practical problem solving relevant to their Science 1 coursework.

In both years, the school had the benefit of a student teacher who acted as liaison officer between the three partners, assisted with the development of the industrial project, visited the company with the pupils and teacher, and obtained feedback from the pupils and staff.

The nature of the link

(i) Its relationship to the National Curriculum

A link between a school and an industrial company can be symbiotic. The company gains public awareness and sympathy towards some of its policies. The school staff and pupils gain a realistic view of how an industry can apply the scientific principles taught in school science, and integrate the necessary skills within the science curriculum. The experience gained by pupils when they undergo their usual period of work experience may be deficient academically, both with respect to subject areas of the National Curriculum and the five National Curriculum cross-curricular themes, namely:

A) Environmental Education.
B) Economic and Industrial Understanding.
C) Careers Education and Guidance.
D) Health Education.
E) Education for Citizenship.

There is clearly overlap between several of the themes, as Industry will give the pupils knowledge of A) above and, in a broad way, B) can be taken into account if the pupils are asked to consider their future when they leave school. The role of industry in the prosperity and social structure of society forms an introduction to aspects of D). If the right industry is chosen, then E) may be relevant to the placement, but only if the pupils are directed towards this theme. Some routes to appropriate guidance towards visiting these themes could be:

Environmental Education.

This theme is devoted to generating a positive attitude to the environment. The environment can be closely linked to many industries with relevance to their policies on pollution control and energy conservation etc. If an industrial visit or series of visits is/are co-ordinated across school subject boundaries, within a link between industry and a school, this cross-curricular theme could be addressed. For example, a short questionnaire could be compiled, based upon the industrial processes involved within the company visited, transport of raw materials and finished products, disposal of waste and so on.. This together with searching questions about the possible policies of the company may get the pupils thinking about several areas which may be otherwise overlooked.

Economic and Industrial Understanding.

Within this theme, the pupils could be asked to think about, and/or comment upon, the way in which many activities within an industry are justified. This should lead to the pupils realising the importance of the financial side of the business, as well as the effect the demands of the consumers (and the governmental policies) might have upon the school management's decisions.

Careers Education and Guidance.

The term "know thyself", is quoted as the central theme in careers education and guidance. Pupils should be aware of what they are capable of, in terms of their strengths and weaknesses, within an academic field. So pupils who were exposed to several aspects of an industry would be more likely to encounter a position which interested them sufficiently for them to follow it up as a possible career. The visit should therefore give a broad view of the types of post available within industry.

Health Education.

Legislation to regulate health and safety at work, COSHH regulations, risk assessment and company medical welfare schemes can all be explored during a link scheme which allows pupils to visit a site on several occasions, so providing sufficient time to explore these aspects.

Education for Citizenship.

This theme should give the pupils the idea that everybody in a community has a democratic right, and that each individual has a part to play in society. With the use of an industrial visit, the problems faced by the management, in terms of the rights of the employees, can be addressed. The relevant areas which may be addressed in detail are the operations of Trade Unions, the economic factors effecting employment and the rights and conditions of the employees.

Objective 1 - a comparison of traditional work experience with the specialised curricular link.

(i) Traditional Work Experience for School Children

One common form of link between a school and industry is through work experience which is a scheme set up during the pupils' last two years of compulsory education. The pupil may be placed in a work experience situation in which:-

a) they are interested,
b) they are useful to the industry,
c) it is beneficial for both pupil and the industry and
d) the pupil gains a realistic view of the working environment.

But frequently, due to shortage of offers, the pupils are placed in an area where often many, and sometimes all of the above points are not met. For example pupils may be used as 'free labour' to do menial tasks so gaining the student little or no relevant experience. This does not occur as a conscious decision by the supervisors, but more because the pupils are placed there with very little collaboration between the industry and the school.

It is the reported experience of pupils that very often the relevant people involved with school links in an industry only have a very short time to prepare the duties for a pupil, so the quickest option is to delegate the menial tasks which require little supervision or training. This can give a wrong impression of a field of work, as the pupils will only see the areas with which they are directly concerned. The industry may be involved with dangerous or technical duties which require weeks or even years of training so it would be unwise to allow a school visitor to attempt these duties.

The remaining duties may be less 'interesting' so giving the impression that the industry is boring to the pupils and that it comprises totally of menial tasks. This may put the pupils off taking up related areas as a career move simply because the choice of placement and duties could have been organised more effectively.

Apart from a few teachers, such as the trained careers teachers, it must be unreasonable to assume that a teacher can co-ordinate and administer suitable relevant duties (by liaising with an industry) unless there are concrete links

within the industry and the subject specialism of the teacher. Such an example would be a technology teacher supervising the choice of duties for a pupil doing work experience in a factory where technology has a major influence.

Work experience is often co-ordinated by one teacher within their area of responsibility. Very often the teacher with responsibility for careers guidance makes the initial contact with firms, but it is increasingly common for this task to fall on the pupils themselves. The quality of the work experience which the pupil receives depends on the attitudes of the firm and the time which it is prepared to devote to the student. So for the placement to be useful for the pupil in terms of academic learning about a situation, the teacher needs to co-ordinate the demands of several subject specialists, or a great deal of help and co-operation from the industry.
It was decided, after the student teacher had collected pupil opinions informally, to obtain feedback from pupils in a more structured way using structured interviews.

Evaluation of previous work experience
During the latter part of the academic year 1991/1992, the year 10 pupils at the school participated in a work experience placement. A selection of the more academically gifted pupils were questioned on their views and experiences during their placement. The following questions were asked in interviews and follow-up questions were added when interesting points were uncovered.
Where did you have your work placement?
Did you have any say where you went?
How long were you there for?
What type of work place was it?
What were the tasks you were asked to do?
What did you enjoy during the work experience?
What did you not enjoy during the work experience?
In what way were you supervised during the time there?
Were you trained to do any tasks? How did you get treated by the employees?
Do you think everybody would enjoy their work experience?
Would you have enjoyed any type of work placement?
Would you like to work at a similar type of place when you leave school?
Did it make you change your mind about future employment? What do you want to do when you leave school? - ('A' levels/H.E.)
Has the work experience helped you in any way?
How do you think work experience could be improved for other pupils?

The answers to these questions above have been transcribed and are included as Section 1 in Appendix 1 to this study.

Of the above pupils and the rest of the pupils in that year, the type of placements were analysed to give the following information:

clerical positions (e.g. office work, building society, etc.)	45%
child care (e.g. nursery school)	27%
shop assistant	18%
veterinary assistant	3%
computer-assisted design	3%
food preparation and distribution	4%

From the pupils comments on work experience several interesting facts emerged One particular pupil gained a Saturday job in a department store as a direct result of this industrial visit. At the opposite end of the success spectrum, a pupil was 'asked to leave' due to the attitude to the placement and the people involved.

The work experience scheme operates on usual business hours. As this is just for one or two weeks this gives the pupils a good idea of the whole working day and not just their shorter school hours. However, this change can prove difficult for some pupils to accommodate. One pupil had major problems with a clothes retail firm. The duties of tidying up an area once the shop hours had finished were to be completed before the staff could leave the premises. The management clarified this point to me, saying that this was a method of encouraging the staff to keep the area for which they were responsible, tidy during shop hours. However the pupil on placement here (who was of below average academic achievement) protested that her 'colleagues' left work before she was allowed to. The connection between this and 'wasted time' during shop hours was iterated to the pupil but either not understood or not agreed. This particular retailer was a supporter of work experience and offered the opinion that this pupil, like many others, was misplaced.

Overall, we may conclude that the usual form of work experience has several shortcomings both in principle and practice.

(ii) The alternative link scheme approach

Addressing Science AT1 - The higher levels

The higher levels, 8, 9 and 10, have been difficult for pupils to reach in Attainment Target 1 as there has been a lack of level 10 investigations produced by the examination boards as exemplars for schools to use with pupils.

This industrial link was designed to address this shortage area and was aimed at the more academic year 10 pupils, to whom the higher levels of Attainment Target 1 are relevant. At levels 8, 9 and 10, an extended investigation required the use of scientific knowledge gained from science lessons.

Teaching the Relevant Theory

It is important that for these higher levels to be addressed in an investigation, the relevant theoretical knowledge must be imparted to the pupils before they attempt an investigation. The scientific models from which an investigation could be derived should come from a similar level (plus or minus one) of the content prescriptive Attainment Targets.

At Key Stage 4, the programme of study indicated that the pupils should "be given the opportunities to develop awareness of science in everyday life. They should study how science is applied in a variety of contexts". This could be developed within an industrial link, as the industry might offer the opportunity for the pupils to be exposed to the scientific principles taught in school, which are used in the 'real' world, i.e. learn in a techno-science context.

The industrial link could also offer the pupils the opportunity to "consider the effect of science and technological developments" which was also part of the National Curriculum Key Stage 4 programme of study.

Within the link formed with Hickings, the knowledge came from Attainment Targets 3 and 4, as the processes involved were of a physical science nature. The investigation derived from the industrial process was designed to be carried out by the more academic pupils, and so the higher levels of Attainment Target 1 would be addressed. The strands which were directly linked to the investigation, both in theoretical knowledge needed to carry out the

investigation and any knowledge which might be relevant to the processes, are:-

Strand (iii) AT3, Chemical Changes. In particular, level 7(f) involved the factors influencing rates of reaction. i.e. temperature. Also level 9(d): the use of scientific information influencing factors associated with a manufacturing process.

Strand (ii) AT9, Energy resources and energy transfer. In the link scheme, all of the levels 7 to 10 in this strand could be integrated into the teaching/learning programme.
These were:-
7(b) understand how energy is transferred through conduction, convection and radiation.

7(c) be able to evaluate methods of reducing wasteful transfers of energy by using a definition of energy efficiency.

8(b) be able to use quantitative relationship between change in internal energy and temperature change.

9(b) be able to evaluate the economic, environmental and social benefits of different energy sources using qualitative secondary sources of information.

10(b) understand that in many processes energy is spread out into the surroundings and shared amongst many particles, so reducing the availability of energy.

Within the course which the year 10 pupils follow, a study of processes which were very closely linked to the investigative problem was done. These acted as a refresher for the pupils to enable them to revise the knowledge needed to address the AT1 criteria.

<u>Pre-link preparatory practical work.</u>
The pupils were given experience of the scientific theory involved with the expected high level of attainment with the science investigation target (AT1). Namely :-

Specific heat capacities of water and metals working with the heat transfer (H = mcQ) equation.
Methods and measurements of energy used to heat water
Steam generator : gas flow meter
Electrical immersion heater : joulemeter
Bunsen burner : gas flow meter
Mains water bath : mains joulemeter

Accurate measurements of the variable to be controlled during investigation e.g. time and temperature with I.T. equipment such as 'Sense and Control' module and 'Vela' unit.

These 'pre-investigation' practicals gave the pupils time to familiarise themselves with the apparatus needed to make accurate measurements of the data expected and to help them realise the variables which needed to be controlled and/or measured.

Finding an investigation from industry

The student teacher carried out a series of visits and, in consultation with the University, the school and the company, produced a 'problem' which, although not actually faced by the company at the time of the link, had been an important issue in the recent past, so giving an air of realism to the exercise. The problem relayed to the pupils at the school was one which was linked to Attainment Target four of the National Curriculum, and so with the physics department at the school. As the pupils concerned had often been involved with discussions within the school over such matters as environmental issues and energy efficiency, the Head of Science advised how to target a question which revolved around a cross-curricular environmental issue.

Introducing the investigation

As a direct introduction to the business of the partner company, Hickings, a visit by the pupils was arranged. The pupils were given a guided tour of the factory, together with a scientific explanation of many of the techniques used in the dying industry. This tour was planned to finish at the problem. The group of pupils watched an employee of the factory fill a bucket with cold water, then heat it to an approximate temperature of 80^{o}C with steam generated at a nearby boiler. The pupils were then asked "What is the best way of heating the water ?"

Under supervision, the pupils were allowed to experiment with the apparatus within the factory, using digital thermometers, stopclocks, rules and tape measures to calculate starting and finishing temperatures, the times taken to heat the water and the volumes of water heated. This work related closely to preparatory experiments carried out in school.

The preparatory experiments and the subsequent investigation, which together formed the extended investigation at the heart of this industrial link scheme, are best described in a sample of pupils' work which is provided in Section 2 of Appendix 1 to this work.

Objective 2 - An evaluation of pupils' progress and perceptions on the traditional and investigative project pathways

This objective was pursued with the questionnaires designed for this purpose. One questionnaire was given to teachers, the other to their pupils. In the 1992 and 1993 studies, year 10 pupils were targeted as this was the year group for which the investigative project was designed. In 1995, the sixth form group containing one pupil who had participated in the year10 project was studied as a follow-up.

It should be noted that due to the upheaval associated with re-organisation and adjustment of staff responsibilities, it was not practicable to follow all the pupils on the investigative project through years 10,11 and 12. In fact only one pupil (identified in year 11 as GCSE candidate no. 1081 and hereinafter as CN1081) was tracked from Key Stage 3 through to year 12. However, the case study showed up some possible weaknesses in the questionnaire and these were pursued in detail prior to analysing the results of the second case study.

Working on the initial prediction that a pupil who had participated in the investigative project would show a significant tendency towards problem-solving characteristics and show stronger student cohesiveness than non-participating students, let us consider the results of the 6th form questionnaire. The column headings are the pupil learning styles (SC - student cohesiveness, OE - open endedness, PS1 - problem solving, RC - rule clarity, PS2 - problem solving check). In the table below, T = total for a given learning style; SD = standard deviation for that style.

student	SC (PS) T/SD	OE (FM) T/SD	PS1 T/SD	RC(TM) T/SD	PS2 T/SD
CN1081	13/1.46	20/1.46	20/1.89	10/0.49	14/1.07
E	10/0.49	30/1.75	32/1.91	12/0.70	17/0.49
F	10/0.49	31/1.40	26/0.70	27/1.36	25/0.9
G	10/0.73	19/1.03	22/0.99	11/1.05	17/1.05
T	11/0.49	20/1.46	19/1.58	18.1.92	14/1.31
A	14/0.93	26/0.70	23/0.45	17/1.18	26/1.16
Mean total	11.3	24.3	23.7	15.8	18.8

These results were quite curious as CN1081 showed a less than average tendency towards student cohesiveness, which should be developed by team problem solving, and an even stronger tendency to traditional teacher-centred method. The scores for problem solving (PS1 and PS2) were more

encouraging, with CN1081 showing a positive tendency of 3.7 and 4.8 respectively, giving an average of 4.25 but this was not significantly more than the open-ended flexible method tendency of 4.3. The teacher's responses indicated a slightly stronger trend towards problem-solving methods than flexible, and a more pronounced move away from the traditional approach - a style favoured by the students, indicating that student preferences do not automatically reflect on the outcome of a single individual's scores, but the results signalled caution and it seemed prudent to carry out a more detailed evaluation of the reliability of the questionnaires using a larger sample size.

For this purpose the results for the whole of year 10 (119 pupils) were selected. The following table shows an analysis of the total scores all learning styles.

m = mean					
s = standard deviation					
class	SC	OE	PS1	RC	PS2
	m/s	m/s	m/s	m/s	m/s
10XC	23.4/4.88	29.3/5.128	27.3/3.048	29.6/4.12	25.6/5.946
10XB	16.6/5.142	27.97/3.98	25.1/4.639	15.86/4.14	22.39/4.59
10XA	17.146/4.167	30.33/4.568	26.4/3.99	15.7/3.968	23.4/4.819
10YE	21.7/3.166	24.7/3.74	27.4/4.625	18.5/3.202	21.75/5.45
10YD	19.1/3.982	27.1/3.305	26.3/2.625	19.9/3.928	19.4/6.455
10YC	20.8/4.656	29.5/6.0	26/3.38	18.9/5.89	25/4.123
10YB	17/4.513	26.5/3.903	28/4.867	19.97/2.328	22/5.398
10YA	17.1/4.56	26.85/4.896	27.38/3.276	14.9/5.159	21.9/5.59
MEAN TOTAL AND SD FOR ALL GROUPS	19.06/2.26	27.3/2.47	26.86/1.035	18.7/2.638	22.44/1.84

The interesting bottom line showed that student cohesiveness seemed to be most strongly linked to traditional teaching (perhaps due to a stronger camaraderie when under strongly imposed external direction, rather like army privates bonding together under the orders of a dictatorial sergeant-

major). However, there was also a stronger correlation between problem-solving PS1 and open-ended flexible than between PS1 and PS2. Again, surprisingly, the link of PS1 and PS2 to social cohesiveness was comparatively weak. The results for individual pupils are shown class by class in Section 3 of Appendix 1 to this work.

Detailed analysis of the class results raised some concern over the reliability of the questionnaire itself as the standard deviations for the scores (1 to 6) were generally in excess of 2 (the notable exception being PS1). It was valid to observe that the questionnaire was not designed to measure absolute values, but only trends, so that the reliabilities of individual questions and indeed of both questionnaires were not an issue of primary concern. However, if it were possible to identify at this stage which questions may be yielding misleading, or at best inconsistent responses, so that the standard deviations of overall scores were high, then this would be useful should further work be undertaken in future.

Reliability of questions on pupil questionnaire.

As our primary concern was with identifying trends in those styles which we hypothesised were most closely associated with investigative problem solving, namely social cohesiveness (SC) and problem solving (PS1 & PS2), the analysis was restricted to these three.

A full statistical treatment was beyond the scope of this work, but to illustrate the problem of question reliability, the category social cohesiveness provided an interesting case and an analysis of standard deviations for each question, class by class is given in Section 4 of Appendix 1. A summary table is shown for completeness on the following page.

Whole Sample Style: social cohesiveness response standard deviations

Date	Group	Q1	Q6	Q11	Q16	Q21	Q26	Q31
27 05 94	10 XA	0.80	1.47	1.26	1.31	1.18	1.58	1.20
10 05 94	10 XB	0.95	1 34	1.40	1.27	1.12	1.28	0.93
23 05 94	10 XC	0.97	1.37	1 .69	1.17	1.48	2.02	1.55
05 03 94	10 YA	0.80	1.03	1.24	1.56	0.94	2.06	0.96
03 05 94	10 YB	0.57	1.18	1.39	1.37	1.23	1.47	1.09
03 05 95	10 YC	1.00	1.66	1.26	1.08	1.65	0.93	1.12
03 05 94	10 YD	1.26	1.49	1.15	1.71	1.23	1.81	1.10
03 05 94	10 YE	0.75	1.15	1.21	1.11	0.94	1.61	1.80
14 12 92	l0K Red	0.52	1.37	1.09	0.94	1.29	0.88	0.73
14 12 92	10K Yellow	0.48	1.46	1.41	1.13	1.53	1.71	0.86
27 03 95	6th form	0.00	1.26	1.11	0.47	0.58	0.37	0.47
Mean SD		0.74	1.34	1.29	1.19	1.20	1.43	1.07

Whole sample mean SD = 1.18

As pupils interact together within a group situation, each group of pupils can be assessed as to their social cohesiveness. This can then be taken with the standard deviation from the mean to assemble a measure of the reliability of how the pupils might respond. One standard deviation from the mean encompasses 66% of the total population. With a maximum range of scores of 6, a standard deviation of more than 1 was, for the purposes of this analysis, taken a criterion of unacceptable unreliability.

Each question within the questionnaire is specific. This will allow us to isolate these specific questions as to the response gained form each pupil, a group of pupils or the whole sample. This data can also be used to isolate ambiguous questions which may have generated a large variance of answers. The individual standard deviations for each question within a style, should allow for an estimation of how reliable the question type might be if it is compared to a less ambiguous guestion asked about the same the same criteria, but in a different way.

The mean standard deviation for the social cohesiveness questions asked to the whole sample is 1.1806, which lay just outside the set criterion. To reduce this value, individual questions were analysed.

Some of the questions are more straightforward than others, even though they are detecting the same style of learning. To illustrate this, questions 1 and 26 can be compared. They both give an indication of how pupils socialise within their group. If a pupil answers question 1 with a low number (i.e. they do get on well with other members of the class), then they might also answer question

26 with a similarly (reversed) low number (i.e. they don't take a long time to get to know everybody by their first name in the class). But in question 26 'a long time' is rather subjective so different pupils might answer differently having different perceptions of the same length of time. Hence question 1 should produce a lower standard deviation. One would also expect that the higher the ability level and age of the respondees, the more reliable the responses. Therefore, looking at the year 12 results, we found that the standard deviation for question 1 was 0.00 but 0.37 for question 26. Taking the whole sample showed that question 26 was indeed the worst with a standard deviation of 1.429. and that for question 1 was the best at 0.736. Removal of question 26 and the second worst (question 6) would reduce the average standard deviation to 1.098.

A different approach is to consider just the mean scores for each question. This is shown below.

Whole Sample Style: social cohesiveness

		response standard deviations						
Date	Group	Q1	Q6	Q11	Q16	Q21	Q26	Q31
27 05 94	10 XA	1.67	3.08	2.54	2.83	2.67	2.46	2.25
10 05 94	10 XB	1.76	2.68	2.79	2.53	3.11	1.79	1.84
23 05 94	10 XC	3.06	3.50	3.69	3.56	3.25	3.31	2.81
05 03 94	10 YA	1.94	2.65	2.47	2.71	2.76	3.00	1.71
03 05 94	10 YB	2.29	1.71	3.06	2.65	2.88	1.94	2.47
03 05 95	10 YC	2.62	2.85	3.69	3.38	3.54	1.54	2.92
03 05 94	10 YD	2.56	2.67	3.00	2.44	3.22	2.22	2.89
03 05 94	10 YE	1.67	5.00	4.83	2.33	2.67	2.50	2.33
14 12 92	l0K red	1.23	2.18	3.00	1.82	2.68	1.36	1.91
14 12 92	10K Yellow	1.35	2.18	2.65	1.88	2.88	2.00	1.82
27 03 95	6th form	1.00	2.50	2.67	1.33	2.00	1.17	1.33
Mean		1.92	2.80	3.13	2.50	2.89	2.12	2.43

Whole sample mean = 2.54

As with the standard deviation test, if we now compare individual means with the overall mean, question 1 is least satisfactory and 16 best, but the rank order is quite different from the previous list: 16, 31, 6, 21, 26, 11, 1.

It is interesting to enquire what patterns may be observed in the questions used for PS1 and PS2. These are shown in summary form in the two tables on the next page, with full statistical information given in Appendix 1 Sections 5 and 6 for PS1 and PS2 respectively.

Whole sample: style - problem solving (PS1) response means

Date	Group	Q3	Q8	Q13	Q18	Q23	Q28	Q33
27 05 94	10 XA	4.04	2.52	2.92	1.75	5.17	3.50	3.54
10 05 94	10 XB	2.89	2.79	2.47	1 .61	5.47	2.84	3.84
23 05 94	10 XC	4.94	3.75	2.94	2.61	4.78	3.53	4.00
05 03 94	10 YA	4.04	2.29	2.76	1.35	4.94	3.71	3.68
03 05 94	10 YB	4.12	3.41	2.76	1 .85	5.03	3.79	3.18
03 05 95	10 YC	4.12	3.00	3.27	2.62	5.12	4.19	5.10
03 05 94	10 YD	4.78	3.00	2.22	2.22	4.94	3.89	4.28
03 05 94	10 YE	4.00	4.00	3.08	2.83	5.00	3.33	3.17
14 12 92	10 K red	4.07	3.00	2.05	1.36	5.27	3.02	3.61
14 12 92	10K yellow	4.06	2.35	3.29	1.88	5.47	3.59	3.18
27 03 95	6th form	2.40	3.00	3.00	3.20	3.80	2.60	3.00
Means		4.03	3.01	2.80	2.12	5.00	3.45	3.69

Whole sample mean = 3.44

Whole sample: style - problem solving (PS2) response means

Date	Group	Q5	Q10	Q15	Q20	Q25	C30	C35
27 05 94	10 A	3.10	2.29	4.52	3.46	3.85	2.35	3.06
10 05 94	10 B	3.18	2.66	4.05	2.68	3.21	2.76	3.84
23 05 94	10 C	4.13	2.63	4.44	3.59	3.22	338	3.88
05 03 94	10 YA	3.35	2.29	4.24	2.79	3.41	2.35	3.47
03 05 94	10 YB	3.50	2.91	3.53	2.65	3.47	2.76	3.18
03 05 94	10 YC	3.38	3.31	4.50	3.96	3.81	2.92	3.56
03 05 94	10 YD	3.76	3.56	4.11	2.44	2.33	3.06	2.94
03 05 94	10YE	4.08	2.83	3.00	3.17	2.92	2.67	3.08
1412 92	10 K red	3.00	2.05	4.18	2.32	2.55	2.27	2.36
1412 92	10 K yellow	3.44	2.12	4.18	2.12	3.94	2.41	2.26
27 03 95	6th form	3.60	2.20	3.40	2.40	3.60	2.20	2.60
Means		3.50	2.62	3.76	2.87	3.07	2.55	3.03

Whole sample mean 3.05

Although it was not appropriate to conduct a thorough statistical analysis, it was useful to note that the social cohesiveness mean scores had a spread of mean +0.59, -0.62 whilst problem solving 1 had a far greater spread of mean +1.56, -1.32 and problem solving 2 was best with mean+/-0.45. Should this present work be extended at some future date to look at the measurement of absolute values of teaching and learning styles, the indications of variability in questions would be an important area for refinement.

Academic progression

During the period of this case study, the school originally involved in the project became amalgamated with a neighbouring boys school so that by the time of the follow-up study in 1995, the sixth form (year 12) science groups containing the year 10 girls in the original study also contained boys. Although these boys were included for comparison, significance was impaired by the small sample size and no conclusions were drawn. The baseline chosen was the Key Stage 3 Standard Assessment Task results and these are displayed in the following table.

Key Stage 3 SAT results 1992

level achieved	number of pupils	% of pupils
unregistered	0	0
1	0	0
2	3	4.29
3	13	18.57
4	27	38.57
5	22	31.43
6	5	7.14
7	0	0
8	0	0
9	0	0
10	0	0

Total number of pupils = 70
mean level = 4.19
Number of pupils in region = 49893
mean level for region = 3.98

Result of SAT for tracked pupil, CN1081, was level 6, placing her in the top 7.14% of her cohort.

G.C.S.E. results 1994

The pupils of interest to us were those who participated (P) in the Hickings project together with those who did not (NP) but were in the same year 12 group in 1995 and the results were as shown in the following table:

Pupil code	Participation	GCSE science grades	year 12 science
a	NP	BB	Y
b	P	CC	N
c	P	XX	N
CN1081	**P**	**B B**	**Y**
d	P	DD	N
e	P	FF	N
f	NP	DD	Y

The results of the questionnaires for these students were discussed at the beginning of this discussion of objective 2 and were inconclusive. The closest approach we could make to a test/control comparison was with pupil coded 'a' and CN1081 who scored equally at GCSE. Pupil 'a' showed a stronger tendency to social cohesion but less tendency to problem solving. This could indicate that CN1081 was a pupil who, by personality was less well suited to the cooperative aspect of team problem solving, but developed superior problem solving skills. However, without comparative questionnaire data for these and similar test/control groups in years 10 to 12, this indication was very tentative at this stage.

Effect of teaching style on learning style

Although it has been noted in the study of 6th form scores that the correlation between teaching style and learning style was unclear, it was worthwhile analysing teacher scores to form a preliminary impression of reliability, prior to looking at a further case study with a larger sample, as was done for pupils. The following tables were based on data obtained in March 1993.

Traditional teaching style

teaching style	corrected scores for teachers					response mean
traditional qu'aire qu. no.	teacher 1	teacher 2	teacher 3	teacher 4	teacher 5	for all teachers
2	6	3	6	2	2	3.8
5	5	6	3	3	6	4.6
8	5	4	3	3	4	3.8
11	1	2	1	1	1	1.2
14	2	4	3	3	3	3
17	4	5	1	2	2	2.8
20	5	3	5	5	3	4.2
23	5	4	6	3	3	4.2
26	4	4	4	4	3	3.8
29	2	1	2	2	3	2
32	2	3	1	1	2	1.8
35	1	1	3	1	3	1.8
	total = 42	total = 40	total = 38	total = 29	total = 35	mean of

mean of totals for teachers for entire category = 37 response means = 3.1

If we now select the four teachers whose total scores are closest to the mean total and also select those questions which give responses of mean +or- 1, we obtain the following table.

teaching style	corrected scores for selected teachers				response mean for all teachers
traditional qu'aire qu. no.	teacher 1	teacher 2	teacher 3	teacher 5	
2	6	3	6	2	3.8
8	5	4	3	4	3.8
14	2	4	3	3	3
17	4	5	1	2	2.8
20	5	3	5	3	4.2
23	5	4	6	3	4.2
26	4	4	4	3	3.8
29	2	1	2	3	2
	total = 33	total = 28	total = 30	total = 23	

mean of totals for teachers for all selected responses = 28.5
mean of response means = 3.45

If we now select only teachers 2 and 3 and look at the spread of their responses, we obtain:

traditional style	teacher 2	teacher 3	response mean for all teachers
qu'aire qu. no.			4.5
2	3	6	3.5
8	4	3	3.5
14	4	3	3
17	5	1	4
20	3	5	5
23	4	6	4
26	4	4	1.5
29	1	2	
	total = 28	total = 30	

mean of totals for teachers for all selected responses = 29.0

mean of response means = 3.6

By adopting the same rule of removing items whose means lie outside the range +or-1, question 29 is deleted.

The questions which remain after this process of elimination are 2, 8, 14, 17, 20, 23, 26.

Flexible teaching style

teaching style flexible	corrected scores for teachers					response means for all teachers
	teacher 1	teacher 2	teacher 3	teacher 4	teacher 5	
qu'aire qu. no.						
1	3	4	2	4	5	3.6
4	3	4	2	3	4	3.2
7	3	3	3	5	5	3.6
10	2	3	2	3	2	2.4
13	4	4	3	2	4	3.4
16	4	5	3	5		4.0
			3			
19	3	5	5	5	5	4.6
22	5	2	1	5	6	3.8
25	2	5	2	3	2	2.8
28	2	5	3	4	4	3.6
31	2	1	1	1	2	1.4
34	4	4	5	2	3	3.6
	total = 37	total = 45	total = 32	total = 42	total = 45	

mean of totals for teachers for entire category = 40.2

mean of response means = 3.3

Firstly we shall discard the teacher whose total is 32 as the deviation is largest. The new mean becomes 42.

If we now select the three teachers whose total scores are closest to the mean total and also select those questions which have a mean within +/-0.5 of the overall, we get the table shown below

teaching style	corrected scores for selected teachers			response means for selected teachers
traditional qu'aire qu. no.	teacher 2	teacher 4	teacher 5	
1	4	4	5	4.3
4	4	3	4	3.7
7	3	5	5	4.7
13	4	2	4	3.3
22	2	5	6	4.3
25	5	3	2	3.3
28	5	4	4	4.3
34	4	2	3	3.3
	total = 31	total = 28	total = 33	mean of

mean of totals for teachers for all selected responses = 30.7 mean of response means = 3.9

Adopting the same exclusion rule as was used for traditional teaching (+ or-1) all the above responses meet the requirement, having survived an earlier +or- 0.5 test. The remaining teachers are sufficiently close to be included.

The questions which remain after this process of elimination are 1, 4, 7, 13, 22, 25, 28, 34.

Problem solving style

teaching style		corrected scores for teachers				response mean
problem-solving qu. no.	teacher 1	teacher 2	teacher 3	teacher 4	teacher 5	for all teachers
3	5	5	1	4	4	3.8
6	5	6	1	2	3	3.4
9	3	4	3	3	3	3.2
12	2	2	1	1	1	1.4
15	1	5	3	3	3	3
18	2	5	3	3	3	3.2
21	2	5	1	3	1	2.4
24	3	5	2	2	4	3.2
27	3	2	1	2	3	2.2
30	3	2	3	4	4	3.2
33	2	5	3	2	2	2.8
36	1	1	1	2	2	1.4
	total = 32	total = 47	total = 23	total = 31	total = 33	

mean of totals for teachers for entire category = 33.2 mean of response means = 2.8

teaching style **problem-solving** qu'aire qu. no.	corrected scores for selected teachers teacher 1	teacher 4	teacher 5	response mean for all teachers
9	3	3	3	3
15	1	3	3	2.3
18	2	3	3	2.7
21	2	1	1	1.3
24	3	2	4	3
30	3	4	4	3.7
33	2	2	2	2
	total = 16	total = 18	total = 20	mean of response means = 2.6

If we now select only those questions where the mean responses is mean+or-1 and include all three teachers as their results are in sufficently close agreement, the questions which remain after this process of elimination are 9,15, 18, 24, 34.

Having established that an acceptably large proportion of the questionnaire items were of reasonable reliabilty for the purpose of investigating trends, we now proceed to the second case study.

Chapter 9
CASE STUDY 2

CONTENTS

Introduction

This case study was intended to have a quantitative emphasis to provide statistical evidence to supplement the work done in the first case study. It also provided a testing ground for the questionnaire.

Objectives

This case study explored the second part of aim 5 which was to:
use the research instrument, together with other evidence, to evaluate the effect of the working model on the learning achievements of pupils at Key Stage 4. The work was carried out in two stages:

(i) The first field test in 1992 was intended to establish the baseline from which to measure differences during the following year.

(ii) The second field test in the following year was to yield information about trends in learning styles. Comparison with the baseline would allow us to evaluate the extent to which differential differences related to the intervention project. Placing this comparison in the context of results from other schools would test the main hypothesis of this work.

Predicted outcomes in the context of the main hypothesis

The intervention project should result in:

(i) An improved attitude to science so that more students opt to study one or more sciences at A-Level;

(ii) An improved grasp of process skills so that pupil achievement in AT1 will be high;

(iii) An improved understanding of scientific concepts producing improved achievement in GCSE examinations.

The company and the investigative project

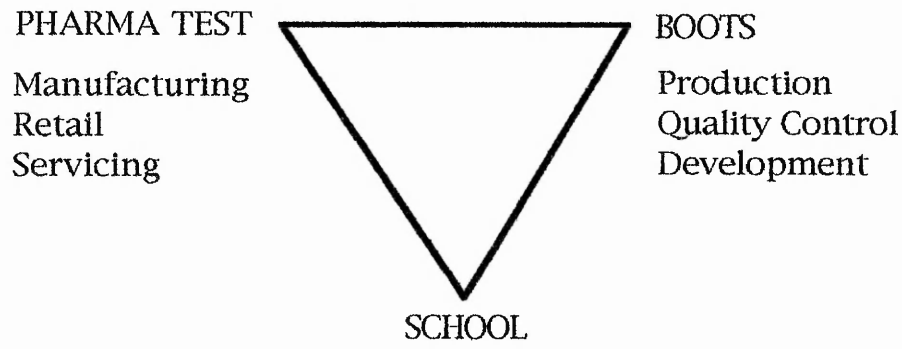
Introduction

The Head of Science at the school approached the Managing Director of Pharma Test UK through contacts made via East Midlands Science Teachers' Action Research (EMSTAR). A period of secondment was arranged using the Understanding British Industry (UBI) Teacher Placement Service and the outcome was an investigative project.

The company

Pharma Test UK Ltd. is a small UK subsidiary of a parent company based in Germany. The main activity of Pharma Test is testing the physical properties of tables manufactured by the pharmaceutical industry. In particular, there is a strong link with the pharmaceutical division of The Boots Company plc. which also has a parent German company. The company carries out research, development and small-scale manufacture of prototype medication in the form of tablets and capsules. The patterns of release of drugs into the human bloodstream must be closely controlled to ensure maximum effectiveness and this is achieved by, for example, varying the thickness and substances used in the tablet coatings. Pharma Test UK Ltd. also has involvement in retailing, service and manufacturing.

In view of the close collaboration between Pharma Test UK Ltd. and The Boots Company plc. a three-way project was established.



Extended techno-science investigation
Curriculum-linked work experience

Objectives of the industry-school link project

1. To provide opportunities for students to carry out an extended techno-science investigation which would give access to the higher levels of attainment in Attainment 1 of the Orders for Science in the National Curriculum (1989).
2. To broaden students' understanding of the pharmaceutical industry, and to increase their appreciation of the technological applications of science in tablet formulation, production and testing.
3. To devise a programme of curriculum-linked work experience in local companies.

As activities similar to objectives 2 and 3 had already been major aspects of the first case study, and had been investigated quite thoroughly, the main focus of this case study was the first objective.

Description of the techno-science investigations

The investigations were broadly scientific in context, drawing upon aspects of Physics, Biology and Chemistry. They comprised a series of investigative tasks based on the physical properties of tablets and their solubilities. Pupils would be required to read background literature, suggest fair tests to investigate the various properties of tablets and thence predict the behaviours of real tablets. They would suggest how to develop fair tests into extended investigations. Three investigations were available and students could select which option they preferred.

Option 1

Many pharmaceutical companies use a hardness test on tablets to provide an indication of the likely solubility rate. Is there a correlation between hardness and solubility? How accurate is this relationship?

Option 2

Tablets are manufactured from powders which are compressed into tablet form. How does the compression force affect

a) the physical characteristics of the tablet and

b) the rate of drug release?

Option 3

In most tablets, the active chemical ingredients are mixed with other compounds known as excipients. How might the type of excipient affect

a) the physical characteristics of the tablet and

b) the rate of drug release?

The teacher in charge of the project would act as mentor, guiding the direction of pupil investigations, so that cross-referencing of pupil work with the National Curriculum enabled pupils to be assessed continually against the criteria for SC1 during the series of investigations which formed the intervention project.

As an integral part of their work, pupils would visit Pharma Test UK to compare their predictions and investigative practical work with reality. Pupils were given background information and procedural guidance for each option as shown below.

Option 1:

1. Refer to the fact sheets on "Tablet Formulation".
2. Devise and test a method to ensure even mixing of the simulated drug (ascorbic acid) in powdered form and excipient (lactose).
3. Design and construct a simple tablet press.
4. Manufacture a range of tablets of different hardnesses. You will need a good supply of each hardness in order to carry out different tests as required in steps 7 and 8.
5. Use the hardness tester loaned by Pharma Test UK Ltd. to measure the hardness of the tablets you manufactured in your press.
6. Refer to the fact sheets on "Dissolution".
7. Carry out dissolution tests to measure the rate of drug release.
8. Compare drug release rates and hardnesses to look for a connection.

Option 2:

1. Refer to the fact sheets on "Tablet Formulation".
2. Devise and test a method to ensure even mixing of the simulated drug (ascorbic acid) in powdered form and excipient (lactose).
3. Design and construct a simple tablet press.
4. Calibrate the tablet press to enable the compressive force to be measured.
5. Manufacture a range of tablet types using different compressive forces. You will need a good supply of each type in order to carry out different tests as required in steps 6 and 8.
6. Use the various items of equipment loaned by Pharma Test UK Ltd. to assess physical properties (hardness, mass, dimensions, friability) of the tablets you manufactured in your press.
7. Refer to the fact sheets on "Dissolution".
8. Carry out dissolution tests to measure the rate of drug release.

9. Look for patterns in your results as suggested in the task specification.

Option 3:

1. Refer to the fact sheets on "Tablet Formulation" and "Type and nature of excipients".
2. Devise and test a method to ensure even mixing of the simulated drug (ascorbic acid) in powdered form and a range of excipients (lactose, starch, cellulose).
3. Design and construct a simple tablet press.
4. Manufacture a range of tablet types using different compressive forces. You will need a good supply of each type in order to carry out different tests as required in steps 5 and 7.
5. Use the various items of equipment loaned by Pharma Test UK Ltd. to assess physical properties (hardness, mass, dimensions, friability) of the tablets you manufactured in your press.
6. Refer to the fact sheets on "Dissolution".
7. Carry out dissolution tests to measure the rate of drug release.
8. Look for patterns in your results as suggested in the task specification.

The school context and pupil performance

The school is an 11-18 Nottinghamshire comprehensive school of some 1100 pupils, 65 full-time and 12 part-time teachers. The school facilities are extensive and include 10 science laboratories which allow choice of balanced science or three separate sciences. In February 1996 the school was inspected under Section 9 of the Education (Schools) Act under OFSTED. In its main findings, the report concluded:

(school X) is a good school. Overall standards are sound and often good throughout the school. Pupils generally have positive attitudes to learning, behave well and achieve well above national and Nottinghamshire averages in public examinations.

The pupils in the test group

Twenty five pupils (4 male, 21 female) worked on the project during the autumn term of year 11. The group was of above average ability, achieving average scores of 66.7% and 76.0% in year 10 and year 11 internal examinations respectively. In the externally-moderated practical skills assessment, the average score was 78.6%. Such pupils were considered to be capable of benefiting from the opportunity to engage with an extended

investigation which would take up to five weeks and provide access to the highest grades (8, 9, and 10) in science attainment target 1.

The teacher of the test group

The member of staff was the Head of Science. He was a very experienced Biology specialist and well suited to manage a bio-chemical project. His teaching style profile is discussed in the second field test results section.

Pupil performance

It was decided to look for differential differences in GCSE achievement by comparing the test group with the cohort before it and with the two following it. These comparisons are shown on the next page.

Comparison of science results with cohort performance

i) GCSE

1992/3 Summary of cohort achievement (year prior to intervention)

Number entered =190 .

% achieved 5+ GCSE's at A* - C = 55.3.

% achieved 5+ GCSE's at A* - G =93.7 .

Subject	Entries	A	B	C	D	E	F	G	U	n/a
Single award	58	4	6	8	13	17	2	4	2	2
Biology	78	21	19	21	8	3	4	1	0	1
Chemistry	80	12	26	19	10	8	5	0	0	0
Physics	82	7	20	26	17	7	3	2	0	0
All science	298	44	71	74	48	35	14	10	2	3

1993/4 Summary of cohort achievement (year of intervention project)

Number entered = 182.

% achieved 5+ GCSE's at A* - C = 56.6

test group % achieved 5+ GCSE's at A* - C = 96

% achieved 5+ GCSE's at A* - G =95.1

Subject	Entries	A*	A	B	C	D	E	F	G	U
Double award	250	16	42	60	58	44	28	2	0	0
Biology	25	1	9	9	6	0	0	0	0	0
Chemistry	25	1	8	8	7	1	0	0	0	0
Physics	25	3	3	8	11	0	0	0	0	0

Test group compared to whole group following same syllabus

Subject	Entries	A*	A	B	C	D	E	F	G	U
Double award	250	16	42	60	58	44	28	2	0	0
whole group	%	6	17	24	23	18	11	1	0	0
test group	24	5	13	3	2	1	0	0	0	0
	%	21	54	13	8	4	0	0	0	0

1994/5 Summary of cohort achievement (year after intervention project)

Number entered = 206.

% achieved 5+ GCSE's at A* - C = 54.

% achieved 5+ GCSE's at A* - G =98 .

Subject	Entries	A*	A	B	C	D	E	F	G	U
Double award	364	38	24	68	82	56	52	38	2	0
Biology	20	2	8	8	2	0	0	0	0	0
Chemistry	20	1	8	6	5	0	0	0	0	0
Physics	20	5	6	6	3	0	0	0	0	0

1995/6 Summary of cohort achievement

Number entered = 195.

% achieved 5+ GCSE's at A* - C = 55.

% achieved 5+ GCSE's at A* - G = 95.

Subject	Entries	A*	A	B	C	D	E	F	G	U
Double award	340	4	34	58	96	50	54	22	14	6
Biology	21	2	7	2	7	2	1	0	0	0
Chemistry	21	2	3	6	6	4	0	0	0	0
Physics	21	2	5	8	4	2	0	0	0	0

Using the above tables we can compare the test group with all science groups and with the cohorts on a year-by-year basis:

Academic year	% pupils gaining A*-C	% pupils gaining A*-G
1992/3 whole cohort	55.3	93.7
all science	63.4	99
1993/4 whole cohort	56.6	95.1
all science	70.4	100
test group	**96**	**100**
1994/5 whole cohort	54	98
all science	58.2	100
1995/6 whole cohort	55	95
all science	56.5	97.6

The overall picture is of a consistent cohort achievement of around 55% in the category 5 or more passes at grades A-C. In science, the curriculum was re-structured for the cohort which sat GCSE in 1993/4 so the 1992/3 results are not strictly applicable for comparison. A very good year for science results in 1993/4 was followed by two years where the science achievement was quite consistent and slightly better than the school average. Set in this context, the results of the test group were very significantly better than the science results as a whole, in a school where overall trends in science results show stability.

ii) Post-16 trends

A high proportion of pupils option to remain at the school for post-16 education and it is therefore appropriate to enquire whether the intervention project had any effect on this phase. This was evaluated using statistics provided by the school in its annual reports and covered A-Level results and numbers of students opting for science. The results for 1995-6 should, if our hypothesis is correct, be affected by the members of the test

group which sat GCSE in 1993-4, as the group comprised pupils of high ability in science who would therefore be likely to stay on into the 6th form, and the differential difference in performance at GCSE level was so large (26%) that its effect might reasonably be expected to show even two years later.

A-Level

1993-4

Subject	Entries	A	B	C	D	E	N	U	n.a.	
AS level	0	0	0	0	0	0	0	0	0	
Biology	22	3	3	4	7	4	1	0	0	
Chemistry	18	0	4	3	4	3	1	3	0	
Physics	24	1	2	4	7	4	4	2	0	
total all sciences	64	4	9	11	18	11	6	5	0	
%	100	6	14	17	28	17	9	9	0	

1994-5 (cohort prior to intervention project)

Subject	Entries	A	B	C	D	E	N	U	n.a.	
AS level	0	0	0	0	0	0	0	0	0	
Biology	18	5	3	4	2	1	3	0	0	
Chemistry	29	6	2	5	5	5	3	3	0	
Physics	22	6	4	2	3	4	3	0	0	
total all sciences	69	17	9	11	10	10	9	3	0	
%	100	25	13	16	14	14	13	5	0	

1995-6 (cohort of intervention project)

Subject	Entries	A	B	C	D	E	N	U	n.a.	
AS level	5	1	0	0	1	1	2	0	0	
Biology	38	5	14	7	8	4	0	0	0	
Chemistry	23	8	4	3	3	2	3	0	0	
Physics	10	5	0	1	1	3	0	0	0	
total all sciences	76	19	18	11	13	10	5	0	0	
%	100			14		13	7	0	0	

Using the 1993/4 baseline, the percentage changes in results were

year	A	B	C	D	E	N	U
1994-5	19	-1	-1	-14	-3	4	-4
1995-6	19	10	-3	-11	-9	-1	-4

The upward trend is marked with the large increase in the percentage of students in the grade A category in 1994-5 being sustained in 1995-6, with an accompanying large improvement at grade B.

Number of students opting to stay on to study science.
From the 1992-3 baseline, the number of students taking one or more sciences increased by 8% in 1993-4 and 19% in 1994-5. These must be seen in the context of a decreasing proportion of students opting for science nationally, so the trend is significantly better than the national picture.

In summary, both these trends confirmed the oral feedback from pupils and staff during the intervention project that the work was interesting and challenging. When taken together with the success of the test group in achieving very high grades in SC1 levels, the effect of the intervention project on pupil performance clearly supported our hypothesis.

Results of the first full field test of the questionnaire - autumn term 1992

Years 10 and 11 were investigated. The year 10 cohort contained the pupils who would participate in the extended investigation the following year. The single science group was taught by the same teacher as the test group, Y10 C.E.X., so was selected as a control group.
Firstly we shall look at the year 10 scores. This cohort was in year 7 when the National Curriculum for Science was introduced. Consequently it was the first year under the National Curriculum.

Pupil group	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.
Y10. B.RP.	14.18/4.28	23.56/2.47	25.56/4.07	21.90/3.91	20.31/5.48
Y10. single science	**19.26/5.76**	**26.66/3.93**	**27.70/2.66**	**20.00/3.43**	**22.93/3.90**
Y10. A.X.	18.47/5.33	24.20/4.65	23.88/3.10	19.20/4.62	19.88/5.53
Y10. C.E.X.	**15.28/4.22**	**26.48/3.17**	**27.60/3.23**	**16.20/3.80**	**21.28/4.44**
Y10. X.Y.HGAM.	20.53/4.39	24.70/4.06	27.60/3.28	21.00/5.96	23.53/4.04
Y10. Y.C.	20.72/5.69	23.22/4.99	27.22/3.10	21.44/4.76	22.05/3.59
Y10. Y.X.	16.21/4.68	25.91/4.77	37.39/3.59	18.71/3.16	20.15/3.88
Y10. Y.	20.10/3.99	26.26/3.09	25.36/3.58	18.28/5.37	20.78/3.99
Av. mean	18.09	25.12	26.53	19.59	21.36
St'd dev'n.	2.37	1.28	1.33	1.77	1.26

The scores for the test group and control groups are almost indistinguishable for problem-solving skills and for open-ended teaching, being separated by differences well below one standard deviation in every case. The test group does, however show a significant tendency towards the traditional style. If this profile is compared with that for pupils of the same age in the first case study shown below,

MEAN TOTAL AND SD FOR	19.06	27.3	26.86	18.7	22.44
ALL GROUPS	2.26	2.47	1.035	2.638	1.84

then we see some interesting similarities: (i) student cohesiveness and rule-centredness are the strongest characteristics; and (ii) open-ended flexible and problem-solving (PS1) styles are least common.

One advantage of this case study over the first one was that a larger group of teachers participated and we may enquire into the question of whether the observed apparent pattern in pupil learning styles bears any relation to teaching style used.
Looking at the teacher styles for these year 10 pupils:

teacher code	**category of teaching style**		
	TM m/SD	FM m/SD	PS m/SD
3	42.00/1.66	30.001.44	18.00/0.95
2	38.00/1.21	33.00/1.19	30.00/1.32
***15**	**36.00/1.22**	**31.00/1.11**	**35.00/1.11**
4	43.00/1.25	22.00/0.55	20.00/0.75
1	45.00/1.48	27.00/1.01	27.00/0.92
8	28.00/1.60	31.00/1.44	38.00/1.67
6	38.00/1.40	27.00/0.60	31.00/1.04
5	36.00/1.78	24.00/1.22	24.00/1.29
9	32.00/1.49	30.00/1.11	34.00/1.40
12	37.00/1.50	26.00/1.07	37.00/1.47
13	40.00/0.94	32.00/0.75	35.00/0.90
14	39.00/1.36	36.00/1.63	35.00/1.11
7	41.00/1.32	33.00/1.23	36.00/0.91
11	35.00/0.95	36.00/0.95	31.00/0.64
10	20.00/1.11	33.00/1.74	37.00/1.38
Av. mean	36.66	30.07	31.2
Mean S.D.	1.45	1.14	1.12

Flexible open-ended teaching seems to be slightly stronger than problem-solving and also has the best reliability as indicated by standard deviation. Traditional (rule centred) is least used, in direct contrast with apparent pupil experience. The member of staff shown in bold type participated in the intervention project, and appeared to have no strong leaning towards problem solving over traditional (within the recognised limitations of the questionnaire)

Next we looked at the scores of year 11. This cohort was in year 8 when the National Curriculum for Science was introduced. Consequently it proceeded under the non-National Curriculum approach and was the last cohort to do so. It is interesting to compare scores with year 10 which was the first cohort to follow the National curriculum.

Pupil group	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.
Y11 CHEM	17.41/4.93	24.39/3.46	24.08/2.81	16.41/4.58	19.94/3.78
Y11 MOD SCI.	16.3/6.29	23.63/3.64	24.08/3.12	17.50/3.94	19.21/4.35
Y11A PHYS	17.69/5.93	24.83/3.79	27.66/5.07	15.78/2.96	20.44/4.97
Y11X CHEM	15.91/3.66	26.35/4.33	24.89/4.04	16.50/4.62	22.85/3.79
Y11A BIO	16.37/3.78	24.28/3.80	24.96/1.95	20.17/4.07	20.52/4.23
Y11 TOTAL	16.74	24.69	25.13	17.38	20.59
AVERAGE					
STANDARD	0.69	0.91	1.32	1.75	1.22
DEVIATION					

There is apparently a marked tendency towards traditional learning methods compared to problem solving, though we claim no absolute value of significance for this pattern as the questionnaire was designed to reveal trends.

Effect of the introduction of the National Curriculum

Some insight may be possible into the effect of the introduction of the National Curriculum by enquiring whether differences in mean scores are significantly greater than mean standard deviations for these two cohorts.

Pupil cohort	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
year11 mean totals	16.74	24.69	25.13	17.38	20.59
standard	0.69	0.91	1.32	1.75	1.22
deviation					
year 10 mean totals	18.09	25.12	26.53	19.59	21.36
standard deviation	2.37	1.28	1.33	1.77	1.26
differences in mean totals	1.35	0.43	1.40	2.21	0.77
mean s.d.	1.53	1.1	1.33	1.76	1.24

On the basis of this elementary analysis, it would appear that, with the sole exception of traditional style, the differences in mean totals all lie within one standard deviation, and that the rank order for preferences - SC, RC, PS2, OE, PS1 - is unchanged.

Differences in learning style which might have been expected from the introduction of the National Curriculum process skills required in Attainment Target 1 are apparently not detectable with this questionnaire.

Results of the second full field test of the questionnaire - autumn term 1993

The 1992 year 10 cohort was re-tested and the intervention industrial project was introduced to the test group in the 1993 year 11 as planned. We may investigate trends by firstly considering differences in means. Secondly these differences may be compared with appropriate standard deviations to establish their significance. Taking the cohort as a whole, the pattern was

style	SC	OE	PS1	RC	PS2
mean total	17.6	24.5	20.5	19.0	19.3

We note that the rank order is the same as the baseline for SC, RC and PS2 but the least popular PS1 and OE are reversed.

Comparing the above scores with those for the same pupils when they were year 10 provides a basic underlying trend pattern as follows:

SC	OE	PS1	RC	PS2
-0.5	-0.6	-6.0	-0.6	-1.9

Taking the cohort as a whole, these results may indicate that the strongest changes were in problem solving skills. The improvement in PS1 is particularly marked and far exceeds the raw trend in problem-solving scores in the test group. The question of correcting for additional factors needs to be considered. For example, it might be the case that some of the improvement was due to the effect of the National Curriculum changes, which might mask the effect of the intervention project. This was looked at in the 1992 field test, but may now be further investigated by comparing the results for two consecutive year 11 cohorts where one was immediately before and the other immediately after the introduction of the National Curriculum (i.e. the 1992-3 and 1993-4 year 11 cohorts).

Comparing the same age group - year 11 - in 1992-3 and 1993-4, we find that

SC	OE	PS1	RC	PS2
+0.9	-0.2	-4.6	+1.6	-1.3

These tables may be combined to find the net effect by subtracting the National Curriculum effect from the first trend. For example, taking the case of SC, the underlying trend was 0.5 towards that style, but the National Curriculum effect opposes this by 0.9, so that the net effect is a trend towards SC of 1.4. The net scores then become

SC	OE	PS1	RC	PS2
-1.4	-0.4	-1.4	-2.2	-0.6

This we shall take as the baseline against which to compare possible trends due to the intervention project. For the test group, the scores before and after the project, and the raw trend are shown below

SC	OE	PS1	RC	PS2
15.7	30.3	20.5	18.7	21.3
17.7	25.2	22.0	19.9	20.3
+2.0	-5.1	+1.5	+1.2	-1.0

The magnitude of the trend relative to the baseline is therefore

SC	OE	PS1	RC	PS2
+3.4	-4.7	+2.9	+3.4	-0.4

This looks somewhat unpromising for our hypothesis which would require a strong negative trend in PS1 and PS2, and probably a move away from traditional style. As a check on these figures, we may carry out a similar analysis for the control group, where, firstly, the scores before and after and the raw trend were:

SC	OE	PS1	RC	PS2
19.3	26.7	27.7	20.0	22.9
19.4	24.8	20.8	19.5	15.6
+0.1	-1.9	-7.1	-0.5	-7.3

The magnitude of the control group trend relative to the baseline was therefore

SC	OE	PS1	RC	PS2
+1.5	-1.5	-5.7	+1.7	-6.7

This indicates a far stronger trend towards problem-solving than was the case with the test group. We may conclude at this stage that the problem-solving skills which we had expected to be enhanced by the industrial problem-solving intervention project do not appear to have been improved significantly. An interesting trend however, is the strongly positive effect of the project on open-ended learning which was a characteristic feature of the Nuffield approach.

As a further check, we shall compare a further group of pupils which took 3 sciences, was taught by 3 different teachers, none of whom participated in the intervention project. These pupils were of particularly high ability in science and might be expected, in view of the larger proportion of their timetable given to science, to have well-formed views on their learning environment in science.
Their scores in year 10 are shown in full on the next page.

Pupil	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.
1	13/1.73	20/1.25	17/1.5	18/1.4	15/1.12
2	13/1.73	22/2.47	15/1.88	12/1.75	12/1.75
3	18/1.18	20/1.25	21/1.93	20/1.25	18/1.55
4	31/1.4	24/1.29	23/1.28	23/0.7	24/0.73
5	21/1.69	31/1.18	24/1.25	19/1.28	25/1.05
6	16/1.28	27/0.83	14/1.07	25/1.4	18/0.9
7	13/1.73	33.5/1.77	18/2.19	15/1.88	17.5/1.87
8	20/1.73	24.5/1.04	24/1.05	15.5/1.06	16/0.88
9	13/1.73	20/175	17/1.5	18/1.4	15/1.12
10	20/1.25	24/1.18	15/1.25	10/0.73	12/0.7
11	14/1.28	26/0.88	21/0.76	17/1.5	22/0.64
12	15/1.73	24/2.06	17/1.68	16.5/1.33	19/1.28
13	20/1.55	24/1.5	23/1.67	23/2.12	16/1.48
14	14/1.69	20/0.64	22/1.25	20/1.36	17/1.05
15	20/1.36	16/0.7	19/1.48	12/1.39	12/0.7
16	14/1.69	21/1.41	22/0.99	24/2.06	15/0.64
17	17/1.5	25/1.4	15/1.99	18/2.19	12/0.7
18	21/1.51	23/1.39	20/1.64	17/1.4	20/1.46
19	17/1.5	19/0.7	24.5/1.1	19/0.7	19/1.03
mean	17.4	23.4	19.6	18	17.1

For ease of reading, the corresponding year 11 scores are shown as a complete table on the next page.

Their scores in year 11 were

Pupil	category of learning style				
	(SC) PS	(FM) OE	PS1	(TM) RC	PS2
	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.	MEAN/S.D.
1	18/1.59	34/1.46	21.5/1.78	24/1.5	36/0.99
2	16/1.28	23/1.58	19/1.67	20/1.96	23/1.83
3	16/1.67	27/0.99	26/0.88	25/1.16	24/0.9
4	12/1.03	30/1.58	19/1.67	13/1.36	29/1.64
5	20/1.12	28/1.07	26/1.03	20/0.99	21/1.07
6	19/1.58	19/0.88	18/1.29	17/1.05	12/0.45
7	21/1.07	22.5/1.36	19/1.03	18/1.05	21/0.76
8	17/1.05	21/1.07	17/1.05	13/0.68	18.5/0.79
9	12/1.39	26/1.91	16/1.48	17/1.67	10/0.49
10	16/1.16	30/0.7	21/1.31	19/1.48	22/1.12
11	21/1.51	30/1.83	24/1.5	20/1.55	32/1.68
12	18/1.18	24/1.5	23/1.67	17/1.5	21.5/1.08
13	17/1.5	22/1.12	21/1.41	17/2.26	16/0.88
14	19/1.03	15/0.99	19/1.28	17/1.18	11/0.49
15	15/0.83	21/0.53	21/0.76	13/0.99	19/0.45
16	21/1.07	21/1.31	24/1.4	17/0.73	20/0.99
17	19/1.03	26/1.48	20/1.55	21/1.31	16/1.28
18	23/1.03	24/1.05	20/0.83	17/0.49	19/0.7
19	15/1.64	26/1.28	21/1.16	25/2.19	18/1.4
20	17/0.73	18/1.8	18/1.8	18/1.59	12/0.45
21	17/1.4	30/1.48	14/1.07	19/1.83	24/1.99
22	23/1.83	29/0.83	24/0.9	22.5/1.46	25/1.18
23	14/1.69	21/1.51	15/1.36	12/0.88	13/0.99
24	18/0.73	19/1.48	18/0.9	20/1.12	21/0.93
mean	17.7	23.6	20.2	18.4	20.2

The trend from year 10 to 11 was therefore

SC	OE	PS1	RC	PS2
+0.3	+0.2	+0.6	+0.4	+2.9

With the sole exception of PS2, these trends were far less than the mean standard deviations in each category, and so have little statistical significance, indicating that no significant trends (which might have influenced the score trends produced by the intervention) took place from one year to the next. It might be argued that the positive trend (shown by decreasing scores) in the test group's scores for PS2, when seen against the negative trend for the 3-sciences group, was encouraging for our hypothesis. However, this slight trend was overwhelmed by the positive PS2 trend in the control group which far exceeded that of the test group.

Chapter 10
Discussion of conclusions and some extensions

At the start of this thesis, five aims were stated (please refer to the appropriate section). Chapter one has addressed the first aim. The second aim was tackled in chapter two, where, in order to establish a theoretical basis for a 'techno-science' approach in secondary schools, the nature of problem solving as an intelligent activity was discussed and related to school science and technology. Chapter three took the discussion further and adapted the work of previous writers in order to devise a three-dimensional representation of the working model for investigations which formed the third aim. This aim was further addressed in chapter four where terminology was clarified prior to a statement of objectives in chapter five and a description of the intervention model in chapter six. The fourth aim was dealt with in chapter seven. Finally, the fifth and main aim underpinning the title of this thesis, was looked at in the case studies in chapters eight and nine.

a) Conclusions

Case Study 1

(i) The first objective set for this case study was:
to compare the school's usual method of delivering work experience for year 10 pupils, with the method of specialised work experience obtained through extended science investigations in the context of the 1991 Orders for Science in the National Curriculum.

In this context, using the pupil questionnaires and interviews held with the pupils during the first year of this project, several interesting points arose from the pupils' expectations of work experience.

Many pupils had formed ideas that they would be undertaking complex duties within their work experience week. This was illustrated by pupils A, D and E. These pupils wanted to be at, or at least introduced to, the cutting edge of the professions . For example some of the pupils who visited a solicitors wanted to experience the duties of a solicitor. This was not forthcoming and the pupils were given secretarial duties within that profession. This was a good experience if the pupils (as many did) wanted to become secretaries, but if the pupils had little experience or skill in secretarial work and wanted to gain knowledge of the specific profession, it became a direct disappointment

for them. When this happened the pupils did not enjoy the week and would have preferred shop work where they could have "met people".

The choice of work experience at this particular school was varied, but the pupils thought it limited. The academic pupils had little choice, if they were to visit a profession where they would:
a) be welcomed,
b) get a realistic profile of the duties of that professional and
c) get something from the visit without being a burden on the staff involved.

Training is the biggest hurdle within a limited time scale of one week's work experience. Pupils who benefit substantially from the time spent usually have some skills which may be vocational or derived from interests (as in the case of a pupil who visited a veterinary surgeon). Pupils with secretarial skills like pupil B, enjoyed working as a secretary. Conversely pupil D placed at a similar establishment had little secretarial skill and although at a similar academic level did not enjoy the duties given.

In some of the cases encountered in this project, work experience can be a very successful method of confirming that a student's chosen career is appropriate, and conversely can highlight problems with a career that they either had not fully understood or about which they had formed misconceptions.

For a student who has little idea of future career, work experience may be 'pot-luck' and pupils may resent the time which they perceive as wasted in a misplacement A possible method of clearing up some of the misplaced cases may be to break up the work experience week into several visits to different industries as a form of induction. This may both prepare the pupils for what is to come and allow them a choice, of when they know what may suit them, rather than select a meaningless job title. Two main penalties inherent in this multi-centre approach are:
a) firstly, from the pupil's viewpoint, superficiality with information being undigested;
b) secondly, from a school view, it may be less demanding on staff hours if a pupil or several pupils were to be located at one site and visited once or twice. During these visits problems from the pupils and management of the premises would come to light.

Although some employers plan programmes of work experience very effectively, a small minority take on pupils for work experience without thoroughly planning a week of duties for the pupil. This may be complicated within a large establishment by consultation between management who may have agreed to take the pupil, and supervisors on the 'shop floor' where the pupil is to fit in with existing work practice. Here in some cases the supervisor of the pupil may only have a few minutes' notice of the pupil starting. This is no reflection on the employer or supervisor in terms of their professionalism as the problems of time pressure are well known, but, with a little forethought, there are cases where interesting, though simple tasks might have been reserved over a period of weeks, which the pupil could subsequently have undertaken.

Pupils can gain many advantages from a work experience placement. One relatively common outcome is be a part-time job. But, of greater significance might be a sense of purpose. This can be illustrated by a pupil who was of low academic achievement, who, for the want of something better to do, took a placement at a school for people with physical disabilities. This resulted in the pupil finding a possible vocation. Because of the qualifications needed for the pupil to be accepted on a nursing course, the pupil really did make extra efforts in her work back at school which she now perceived as giving her a better chance of reaching her goal.

Overall work experience placements produce some degree of pupil learning, and even where the pupil has a disastrous time on the placement, something is learned from the mistakes. Yet, since education in a broad sense is the objective, the vehicle of work experience must be employed to complement the pupil's academic education especially in term of the cross curricular themes outlined in the introduction to this case study.

The pupils at the school in the first case study who opted out of their work experience week all gained the chance to obtain the higher levels for their science investigations. The question must be asked whether they were deprived of any valuable experience by not participating in normal work experience. The answer to this is largely conjecture as insufficient time prevented a full analysis of this dimension. Possibly, as the pupils were of above average Intelligence and would probably be entering the sixth form (as illustrated in the 1995 follow-up) they only missed an opportunity to 'taste' a profession they would probably not take up after leaving school. It

could be argued however, that they failed to get out into the 'real world', to mix with adults as 'equals' and as one pupil put it "get away from the over-protection of the school". The latter of these points may well be at the heart of the work experience philosophy. As such, the project pupils sacrificed breadth in order to achieve depth, a common experience for those aspiring to excellence in any field of endeavour.

(ii) The second objective for this case study was to carry out an evaluation of pupils' progress and perceptions on the traditional and investigative project pathways. Some discussion of the results and implications for questionnaire design have been discussed in the case study. However, there are further issues which arise.

1. The values of means for the whole group involved in the study show that student cohesiveness (SC) is less strongly correlated with problem-solving type 1 (PS1) and problem-solving type 2 (PS2) than the latter two are with each other. This provided some understanding of the earlier pattern in the observations for the 6th form where the test pupil showed a below average score for social cohesion, whilst also displaying an above average tendency towards problem solving.

To illustrate this point, the trends in PS1 and PS2 for this pupil are shown below.

Style PS1 before intervention project

Q3	Q8	Q13	Q18	Q23	Q28	Q33
5.0	1.0	1.0	2.0	5.0	5.0	2.0

Mean score for PS1 = **3.0**

Style PS1 after intervention project

3.0	1.0	1.0	1.0	5.0	1.0	4.0

New Mean score for PS1 = **2.3**

Style PS2 before intervention project

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	1.0	3.0	2.0	3.0	2.0	3.0

Mean score for PS1 = **2.3**

Style PS2 after intervention project

3.0	1.0	4.0	2.0	1.0	1.0	2.0

New Mean score for PS2 = **2.0**

Both mean scores show a trend towards problem solving, but whether this is the direct result of the project is difficult to establish with such a small sample.

2. The nature of the case study with the difficulties of school amalgamation during the study and small sample available for a longitudinal study provide a relatively weak basis on which to base conclusions regarding trends in learning and teaching styles arising from the research intervention.

3. There is some evidence that questionnaire items were not of equal reliability and some questions were sufficiently at variance with the mean scores to raise concerns about their appropriateness. A full statistical analysis of the reliabilities of questionnaire items would form a suitable topic for future research, but, having visited the issue, we needed to proceed to a further case study where a larger sample of students and their teachers could be followed longitudinally.

Conclusions from Case Study 2

Based solely on the data from the questionnaire, the incremental differences i.e. the changes in the stylistic differences as determined by measurements before and after the intervention (central to the second objective of that case study, namely to look for trends in teaching and learning styles) do not yield a consistent pattern. The conclusion from the results of this aspect of the case study would be that the initial hypothesis has not been demonstrated.

However, feedback from the teacher involved in the case study intervention project should be noted. In a letter dated 17.1.95, he wrote, "It (the tablet investigation) worked extremely well, and some high marks - many 9's and one 10 - were awarded. These remained unchanged after external moderation. I do intend to continue such investigations as coursework assessments - which is a development that was originally intended."
Such anecdotal evidence should be placed in balance with the results of a prototype questionnaire.

Furthermore, the statistical evidence from our analysis of trends in the number of students opting to study science at A-Level, and the achievements of the test group in GCSE examinations and AT1 skills, all point to the success of the predictions based on the hypothesis.

This case study yielded statistical information superior to that of the first case study and we may conclude that, in relation to the hypothesis:
(i) Based solely on the data from the questionnaire, the differential differences (central to our second objective) do not yield a consistent pattern and would need further work.
(ii) The statistical evidence from our analysis of trends in the number of students opting to study science at A-Level, and the achievements of the test group in GCSE examinations and AT1 skills, all point to the success of the predictions based on the hypothesis.
(iii) Feedback from the teachers involved in the intervention project, such as comments on perceptions of pupil interest, motivation, attitudes and work rate, are valuable even if subjective and anecdotal, and should supplement the quantitative results of a prototype questionnaire which was restricted in scope and of uncertain reliability.

b) Limitations of the study

A number of limiting factors need to be recognised in this study:
(i) In classroom reality, some overlap of indicators in the teaching and learning categories is inevitable. For example, a problem-solving style shares some features with the flexible style, and so a degree of artificial dichotomy was introduced to provide models of styles which are sufficiently differentiated to facilitate research of possible trends.

(ii) It is also recognised that the approaches of teachers form a continuum. For example, some teachers may have characteristics across the full spectrum, and for others the predominant approach varies according to the age, behaviour, ability and aptitude of each class, time of day, proximity of holidays and other factors which have psychological effects.

(iii) The nature of the intervention project was constrained by schools having a syllabus to follow and other external pressures such as league tables of GCSE results and OFSTED inspections.

(iv) The changing nature of the National Curriculum Orders for science which occurred during the period of this work produced a strong swing towards content-oriented teaching and away from extended investigations, so restricting the scope for carrying out intervention projects in a larger

number of schools. It is most commendable that the two schools which became case studies persevered with this work despite negative pressures.

(v) Teachers reported that their responses in the questionnaire depended on the nature of the class. It would be useful to use the built-in cross referencing in pupil and teacher questionnaires to explore the extent of this. It was thought by many respondents that the questionnaire highlighted a difference between what they would like to do and what in practice they were able to achieve.

(vi) Ambiguities in teacher responses arose due to point (v) above. It would be possible to disentangle these two strands with follow-up interviews, but these were not practicable in the present study due to time constraints on both sides.

(vii) There was evidence (particularly in the first case study) that questionnaire items were not of equal reliability and some questions were sufficiently at variance with the mean scores to raise concerns about their appropriateness. Despite this, errors arising from such questions would be mitigated when using the differential difference approach in the study. It follows that the use of the questionnaire to explore trends was theoretically defensible.

(viii) The first case study was weakened organisationally by difficulties of school amalgamation during the study. Statistically, the small sample available for a longitudinal study provided a relatively weak basis on which to base conclusions regarding trends in learning and teaching styles arising from the research intervention.

Suggestions for extension work

1. The present work focused largely on a horizontal study of year 10 pupils as this year group was selected for participation in the industry-linked investigative problem solving practical projects. However, the questionnaires were used with year 11 and some year 12 pupils. The teacher questionnaire was also used with students at university undertaking initial teacher training, research students and university lecturers. It is certainly feasible to undertake longitudinal studies, following for example a sample of children through secondary schooling and - as the percentage of pupils staying on into tertiary education continues to grow - on into higher

education. Another interesting study would be observing the development of teaching styles in science teachers, from their first entry to an I.T.T. course, through periods of teaching practice and on into their professional careers. Used in this way to study trends, little further work would be required to refine the reliability of the questionnaires.

2. The questionnaire design allows cross-linking of teacher and pupil perceptions of the same teaching and learning environment. For such a study to be undertaken, a full statistical analysis of the reliabilities of each question would have to be undertaken to extend and refine the preliminary consideration of this topic touched on in Case Study 1. The school surveys which were undertaken through the original E.M.S.T.A.R. (East Midlands Science Teachers Action Research) group of 24 teachers yielded a statistically significant return of over 1000 questionnaires. These covered comprehensive schools, schools for pupils with special educational needs, a sixth form college, primary schools and a college of further education.

Such extension work would allow the results of the questionnaires to be used not only to identify trends as in the present work, but also to yield absolute values. This information could inform discussion of the effectiveness of science teaching methods in influencing learning styles. It could also be used to study the relationship of learning styles to pupil achievement in various forms of assessment.

3. In 1983 the author of this work was awarded a Teacher Fellowship by the Institution of Mechanical Engineers to develop science investigative practical set in a context which linked GCE Physics to applications in local industry (McKenzie 1984 [1]). Some 13 projects were produced and in1994 he introduced a technological problem-solving project for year 10 pupils into the Physics scheme of work. The following year when the GCE O-level results were published, it was possible to evaluate the effect of the project of pupil achievement. Generally, the pattern of results was that about 10 pupils in the top set achieved grade A. The results of the test group of 27 top set pupils (following the same syllabus as the previous year, taught by the same teacher) were far superior (18 grade A and the remainder grade B). Video films and published reports of this project have been mentioned earlier in this work. It is important to note that the number of schools participating in this work, and the extent to which participating schools integrated contextualised extended practical investigations into their science policies,

were severely impaired by changes to the Orders for Science in the National Curriculum in 1994.

It is therefore interesting to compare briefly the UK situation with that in developing countries where curricular reform is underway. Taking the case of Africa, several science educators in the late 1980's and early 1990's called for curricula with greater relevance to local needs and applications (Ogunnuyi, 1988 [2], Sifuna, 1992 [3]). Swift,1992 [4] suggested that a technological component of the science curricula in developing countries, including indigenous technology, may increase the relevance of learning. As a result, several countries inaugurated reform in science education - Botswana (Nganunu, 1988 [5]), Zimbabwe (Robson, 1992 [6]), Ghana (Yakubu, 1992 [7]), Swaziland (Dlamini, 1993 [8]), Sierra Leone (Baimba et al. 1993 [9]), ANC 1994 [10] and Mozambique, 1994 [11].

In the case of Swaziland, Dlamini [12] wrote of the secondary sector:

> The problem is not that science is not taught today; but the problem is the way science is taught, where the recalling of facts is more important than applying those facts for scientific deduction of information, and then using that information to explain what happens around us and how the information can be used to benefit us.

Putsoa's study, 1992 [13] of senior secondary school science students in Swaziland showed that the 'facts' of science may be known, but make up isolated knowledge. For some years, senior science educators in Swaziland have argued for the increased relevance of science education through a broadening of the curriculum content. The Vice-Chancellor of the University of Swaziland (Makhubu, 1988 [14]) suggested integrating the use, scientific basis and social relevance of Swazi indigenous technology in the science curriculum.

One response to this has been the development of collaborative UK-African science INSET strategies such as the one between Swaziland and the University of York (Lubben et al. 1995 [15]). Lubben reported that the project facilitated the production of learning materials for two units in the junior secondary science syllabus in Swaziland. The new materials called the Matsapha Lessons, replaced the standard SWISP (Swaziland Integrated Science Project) and have a technological approach characterised by three aspects:

(i) contextualisation - linking science to everyday life and student experience;
(ii) application - helping students to select and apply their science knowledge to solve problems;
(iii) investigation - developing science investigative abilities to help students to design and execute valid practical tests.

Summarising the outcomes of the project, Lubben reported in 1996 [16]
a) Students' responses to the contextualised lesson materials indicated their surprise that learning school science can be combined with the acquisition of knowledge useful to daily life;
b) students' interest in learning science is stimulated by contexts with which there are perceived to be immediate or future personal links;
c) Overall, the findings show that contextualization has a potential for encouraging student participation in science lessons, strengthening active learning and moving teachers away from traditional teacher-centred instruction.

It would therefore be particularly satisfying to follow up national studies by exploring international comparisons through collaboration with colleagues in Africa and Australia whose work with questionnaires provided the model from which the questionnaire in this thesis was derived.

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APPENDIX 1

Outcomes and observations from Case Study 1

Section 1	Transcript of work experience interviews with selected year 11 pupils
Section 2	Sample of pupil's work showing preparatory experiments and the main practical investigation
Section 3	Pupil questionaire response analyses: all learning styles for year 10 pupils
Section 4	Pupil questionaire response analyses: social cohesiveness style for year 10 and year 12 pupils
Section 5	Pupil questionaire response analyses: problem solving (PS1) style for year 10 and year 12 pupils
Section 6	Pupil questionaire response analyses: problem solving (PS2) style for year 10 and year 12 pupils

Section 1 - Transcript of Work Experience Questionnaire

The questionnaire was given orally to a selected few, more academic, year 11 pupils, about their work experience week during their year 10. This provided a fair comparison on the basis of ability level with the pupils who participated in the link project with Hickings.

Pupil A

Where did you have your work placement?
Robert Barber Solicitors.

Did you have any say where you went?
Yes.

How long were you there for?
Just a week.

What were the tasks you were asked to do?
I couldn't really do much because the people that were there were really experienced. I did some conveyances and read some cases. Mainly paperwork and the easy ones.

What are conveyances?
I don't really know.

What did you enjoy during the work experience?
We went to the court once....I had never been to a court before.

What did you not enjoy during the work experience?
Not being able to do as much as I wanted to do. The week was boring. Very boring.

What would you have liked to have done instead?
To be honest I would have rather have gone to a shop, at least I would have got to do something and meet people.

In what way were you supervised during the time there?
I wasn't really supervised, the manager was too busy. A secretary looked after me most of the time. I talked to her most of the time, but apart from that I didn't have much supervision.

Were you trained to do any tasks?
No.

How did you get treated by the employees?
Really nice. They were all really nice people.

Do you think everybody would enjoy their work experience?
No. Not if they went to a solicitors unless it was a big firm like The Prudential. This was a small firm with not many staff so I didn't meet many people.

Who do you think did enjoy their work experience?
Pupils who went to shops and met a lot of people. It was those who wanted to do that job when they left school.

Would you like to work at a similar type of place when you leave school?
No. I didn't want to do it anyway but I didn't want to go to a shop.

Did it make you change your mind about future employment?
Yes. Definitely. I definitely do not want to be a solicitor.

What do you want to do when you leave school?
I want to be a contemporary designer. Do 'A' levels and go to university.

When did you decide this?
About nine months ago.

Has the work experience helped you in any way?
It made me decide what I didn't want to do.

How can work experience be improved for other pupils?
They could be shown around the place before they go. They should be interviewed by the firm before they take them on. They should be allowed a wider range of jobs - we had the choice of either shops, banks or solicitors.

Do you think work experience is a good idea?
It gives you a task if you go into a shop and it is helpful if you want a Saturday job. But you have got to have all the qualifications to be a solicitor and you could not possibly know it all in one week.

Pupil B

Where did you have your work placement?
O'Connors Solicitors.

Did you have any say where you went?
Yes, we had to choose what type of firm we wanted to go to.

Why did you choose a solicitors?
Because it sounded more interesting than a shop.

How long were you there for?
1 week.

What were the tasks you were asked to do?
Audio-typing and we went into court.

What did you enjoy during the work experience?
I enjoyed it all. It was a laugh. There was another person there with me from a different school.

In what way were you supervised during the time there?
The receptionist was there for us all the time.

Were you trained to do any tasks?
The audio typing.

Do you think everybody would enjoy their work experience?
It depends where they went. If they didn't know where they wanted to go and just picked anywhere they didn't enjoy it. I picked a solicitor because I thought it would be interesting and it was. One person chose a solicitor but didn't enjoy it because they could not type. As I could type, I got on better.

Would you have enjoyed any type of work placement?
Probably.

Would you like to work at a similar type of place when you leave school?
No. It is not the type of thing I want to do. I want to be a teacher.

Did it make you change your mind about future employment?
No.

Why did you not go to a school rather than a solicitor if you wanted to be a teacher?
Only primary schools were available.

What do you want to do when you leave school? - ('A' levels/H.E.)
'A' levels and then university.

Has the work experience helped you in any way?
It helped me to talk to people. It brought me 'out of my shell'.

How do you think work experiences could be improved for other pupils?
Find more things for you to do. In the place where I went they did not know I was going. They hadn't told the other staff. The receptionist didn't know I was going until I arrived, and she could have saved some work for me to do.
Do you think work experience is a good idea? Yes. It allows you to mix with adults.

pupil c

Where did you have your work placement?
Mansfield and Sutton Observer.

Did you have any say where you went?
Yes. We had three choices and the teacher rang up each choice in turn until a placement was found.

How long were you there for?
1 week.

What type of work place was it?
Newspaper.

What were the tasks you were asked to do?
We spent 1 day in each department; Editorial, Administration, Sales, Reception.

What did you enjoy during the work experience?
The Editorial because I like English and I wrote a piece about gardens as well as writing the horoscopes. I also enjoyed being in reception with the fax machines and the typing.

What did you not enjoy during the work experience?
The first day was 'dead line day' (sic) and so they could not fit anything useful in. I just had to sit there and do nothing.

Would you have enjoyed any type of work placement?
No. A lot of people went to a solicitor's. That did not appeal to me as I was not interested in that.

Would you like to work at a similar type of place when you leave school?
Yes, but only the journalism side.

Did it make you change your mind about future employment?
No, but it helped me decide.

What do you want to do when you leave school?- ('A' levels/H.E.)
'A' levels then university - hopefully. Then a journalist or a teacher.

Has the work experience helped you in any way?
Yes. It gave me a insight into work.

How do you think work experiences can be improved?
Let them see the place before they go to it for the week. A day visit would stop people wasting a week on something they find really different from as they expect.

Pupil D

Where did you have your work placement?
Bryon and Armstrong Solicitors.

Did you have any say where you went?
Yes.

How long were you there for?
4 days.

What type of work place was it?
Solicitors.

What were the tasks you were asked to do?
Filing, making out bills, searching through files.

What did you enjoy during the work experience?
Going to the Magistrates court.

What did you not enjoy during the work experience?
The boring clerical work.

In what way were you supervised during the time there?
Everybody who was there supervised me.

Were you trained to do any tasks?
No .

How did you get treated by the employees?
Alright. Because they were busy they didn't have a lot of time to speak to me, but when they did they were nice.

Do you think everybody would enjoy their work experience?
No. Only people who could type would have enjoyed working at a solicitors because that is all they wanted you to do. If you couldn't' do basic office jobs - that they thought was basic - you couldn't do anything.

Would you have enjoyed any type of work placement ?
No. Not where I was stuck in an office and that was it.

Would you like to work at a similar type of place when you leave school?
Yes. But not in the clerical side of the solicitor. I want to be a solicitor rather than a secretary.

Did it make you change your mind about future employment?
No. I went there because I wanted to be solicitor.

What do you want to do when you leave school? - ('A' levels/H.E.)
'A' levels, university.

Has the work experience helped you in any way?
Yes. It has helped me see what a solicitor actually does rather than what I think a solicitor does.

Pupil E

Where did you have your work placement?
The Halifax.

Did you have any say where you went?
Yes.

How long were you there for?
1 Week.

What type of work place was it?
Building Society.

What were the tasks you were asked to do?
Updating the account books and filing.

What did you enjoy during the work experience?
Nothing. It was boring.

What did you not enjoy during the work experience?
Working on the computer everyday, doing the mail and filing.

In what way were you supervised during the time there?
Everybody.

Were you trained to do any tasks?
I was trained to work on the computer and how to operate the franking machine.

How did you get treated by the employees?
I didn't really talk to them.

Do you think everybody would enjoy their work experience?
No. People would have their own choices of what they would like.

Would you have enjoyed any type of work placement?
I would have preferred a job where I could talk to people more.

Would you like to work at a similar type of place when you leave school?
No.

Did it make you change your mind about future employment?
Yes.

What do you want to do when you leave school? - ('A' levels/H.E..)
'A' levels, University and then definitely not work in a building society or a bank.

How do you think work experience could be improved for other pupils?
The pupils could look around the business first. I was sent to the wrong department. I wanted to go to the cashiers department.

Section 2 - Sample of pupil's work showing preparatory experiments and the main investigation

This sample has been taken from the pupil's file exactly as it was written and the page numbers are the pupil's

CONTENTS

INTRODUCTION

As a group of four, we have volunteered to substitute our year 10 work experience with something which involves more social matters, and that has to do with science. The familiar location which will be our centre of study is the

Hickings Pentecost Ltd.
Queens Street
Nottingham.

Last year, which was the first year of the industrial link, was focused on the background of Hickings, but now, in the second year we are going to explore in depth, the scientific principles involved with the Hickings Plant. The first two days of the week commencing the 5th July 1993, will be used to get familiar with the equipment we might need to deal with when the problem is presented to us. A number of experiements will be carried out using different, available resources. We then intend to visit the Hickings industry itself to see for ourselves what our task is, and either how the problem arose or how it is presently being dealt with.

This investigation will surely take up more than just 5 days; which is the set time for the 10th year work experience. After these 5 weekdays, work left to be finished will be completed in the regular science classes during school hours plus there will be an amount of work which will needed to be completed at home.

Whilst doing this investigation we are hoping to gain more than what we might do, from the normal work experience. We are hoping to gain a reasonable amount of industrial awareness as well as knowledge of the working world.

QUESTIONNAIRE ON HICKINGS

1. **Where is the Hickings factory?**

   Hickings Pentecost Ltd.
   Queens Road
   Nottingham

2. **How are the employees paid?**

   They are paid according to the number of hours they put in.

3. **What is meant by 'clocking on'?**

   This is a system of recording the time of arrival at work, it is only for the manual workers and not the staff. Other factories could have signing in systems where the employees have to sign in and out indicating the times.

4. **What is meant by 'shiftwork'?**

   This kind of work is working in teams at different parts of the day or night. Hickings do two 12 hour shifts or five 12 hour shifts for 60 hours/week.

5. **What is 'flexi-time'?**

   Flexi-time is when the employees can please themselves how long they work, they may work on Saturdays and Sundays. They receive the basic pay rate for up to 40 hours, if they decide to work for longer than this they get paid 1½ of the basic rate.

6. **Promotion within a company depends mainly on a mixture of:-**

   getting on with the boss, training, qualifications, motivation and the want to have to do the job.

7. **Selection of a successful job applicant at age 16+ rests mainly on a mixture of:-**

   personal appearance, qualifications and good motivation in answers to questions. All core subjects are essential, also proof of any previous work or work experience are considered.

8. **What happens to any profit made by the company?**

   Profits mainly go to the shareholders, paying the shareholders keeps the business going, if they do not get paid it might result in the closing down of the factory. Some of the money is reinvested in machinery because without new machinery industries cannot compete. The rest of the money is set out to pay for assets, labour and insurance.

9. What is the approximate number of employees at Hickings?

The approimate number of employees is 100, due to it being a small factory.

10. What are the products at Hickings?

The products at Hickings are net curtains, dyed fabric, dresses, fabric which has been dyed and finished, silk and upholstery.

11. What is the number of school leavers recruited at Hickings/annum?

The number recruited is 0. There is a prospect training YTS system, ET - employment training and the school leavers have to be trained.

12. What is the ratio of men:women?

The ratio of men:women is about 10:1.

13. What is the main work in the laboratories?

The main work is inventing new dyes. It provides a service for inventing dyes which have been asked for by a customer. Here they are invented in small, sample quantities to prevent a waste of materials, this is called Pilot dyeing. Also after dyeing, the fabrics are tested here.

14. What sort of energy is used to heat the water in the factory?

Steam is used to heat the water. The steam is produced by burning coal. Small pieces of coal are brought in specially for this purpose. Coal is used because it is very much cheaper than electricity.

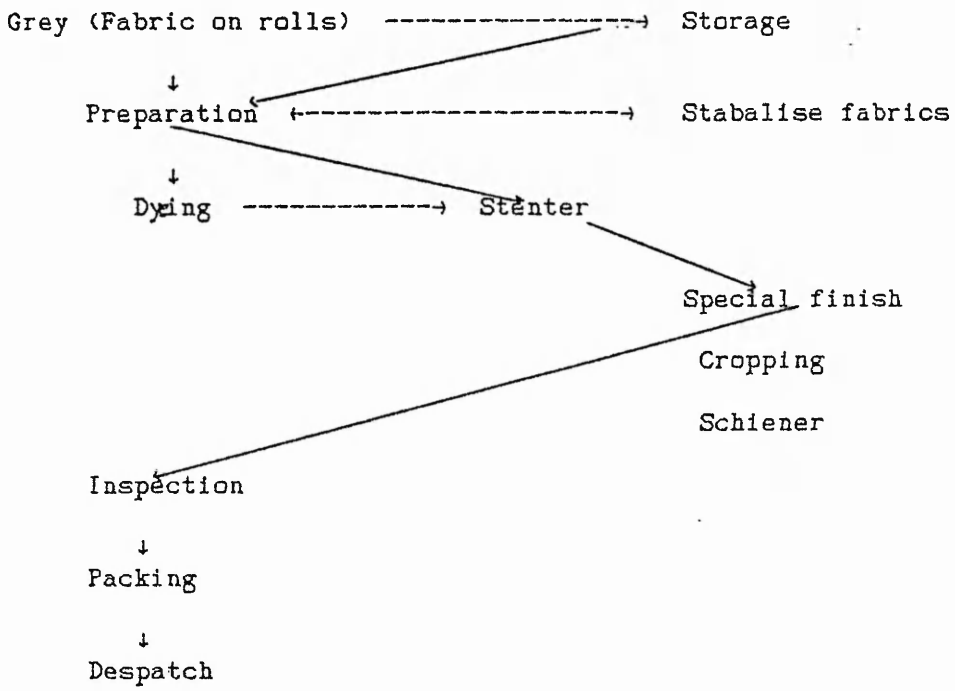
15. Who are the customers for Hickings?

Hickings mainly supply their fabric and nets to the Midlands, their curtains to Scotland and laces to Nottingham.

Hickings

This firm does not produce anything. The raw material or 'grey' material is dyed and finished - so adding a quality value to the product. The firm has a number of product managers. The product managers, with the co-operation of the line supervisors, who have the technical knowhow, process the order through the factory. The success of the firm, is very much dependent on the product managers' technical knowhow and experience to get the product right the first time.

The route the fabric might take is:



EXPERIMENTS — FOR KNOWLEDGE AND UNDERSTANDING

To start off with, practical tasks are needed to be carried out to become familiar with the equipment and to generate the knowledge needed.

5 different experiments are needed to be done, to cover 5 different methods of heating water to get reliable positive results. The experiments done are as follows:

Experiment 1 To find the energy supplied each second from a Bunsen burner.

Experiment 2 To find the energy supplied each second by an electric immersion heater.

Experiment 3 To discover the effect of heat on a quantity of water.

Experiment 4 To discover the effect of the same amount of heat on different masses of water.

Experiment 5 To discover the effect of the same amount of heat on the same masses of different substances.

Each experiment has been described and explained, indicating the apparatus used, the procedure carried out, any alterations to the set experiments and full explanations of the results, finishing with a conclusion.

Experiment 1

AIM

To find the energy supplied each second from a Bunsen burner.

APPARATUS

* gas flow meter
* Bunsen burner
* computer

PROCEDURE

- The gas flow meter is attached to a computer, to record different factors other than just the amount of gas used; such as the total volume in m3. the flow rate in m3/h, the total energy in MJ and the total cost at a therm price of 44.3p
- The gas flow meter is connected to the gas supply
- The Bunsen burner is used for 5 minutes
- All the results are recorded

The test was kept fair by keeping the roaring flame constant.

RESULTS

Time = 5 minutes
Amount of gas used = 4.4 litres
Total Volume = 0.0044 m3
Flow Rate = 0.0458 m3/h
Total Energy = 0.1676 MJ
Total Cost Therm Price 44.3p = 0.0707p

The total energy used here has been converted into Joules by using the following method:

1000J = 1KJ
1000KJ = 1MJ

=> 0.1676 MJ x 1000
=> 167.6 KJ x 1000
=> 167600 J in 5 minutes

$$\Rightarrow \frac{167600}{5} = 33520/\text{min}$$

$$\Rightarrow \frac{33520}{60} = 559/\text{sec}$$

CONCLUSION

If the flame is kept constant, the amount of gas used remains constant, but when the flame is altered the amount of gas used changes. If the flame is reduced, less gas is used and if the flame is increased more gas is used.

Experiment 2

AIM

To find the energy supplied each second by an electric immersion heater.

APPARATUS

* immersion heater
* power supply
* joulemeter
* stop watch
* water in a metal container

PROCEDURE

- The power supply is connected to the 'input' terminals of the joulemeter
- The immersion heater is connected to the 7A outputs of the joulemeter
- The immersion heater is put into water and the circuit is checked
- The joulemeter is then put back to zero
- The immersion heater is switched on for 5 minutes before it is switched off
- The total energy supplied is the reading on the joulemeter
- The energy supplied per second is worked out and recorded

RESULTS

Time = 5 minutes

Reading on joulemeter = total energy supplied
Reading at the end of 5 min = 116 x 100 J
= 11600 J

The amount of energy supplied per second can be calculated by doing the following:

$$\text{In 1 minute} \Rightarrow \frac{11600}{5}\ \text{J} = 2320\ \text{J/min}$$

$$\text{In 1 second} \Rightarrow \frac{2320}{60}\ \text{J} = 38.67\ \text{J}$$

The reading obtained from the Joulemeter need not necessarily be exact. The display could have been a number which has been rounded either up or down to it's nearest whole number
eg. 116(x100 J) could have been 115.5 to 116.49 (or 116.5) and if this had been a decimal, the answer for the energy supplied per second could have been a number with a longer decimal value.

CONCLUSION

Using the immersion heater - Amount of energy supplied in 1 sec = 38.67J
Using the Bunsen burner - Amount of energy supplied in 1 sec = 559J

COMPARING EXPERIMENT 1 WITH EXPERIMENT 2

In 1 second more energy is supplied with the Bunsen burner when compared to the amount of energy being supplied with the immersion heater. This is because the Bunsen burner gives out instant heat where as the immersion heater takes some to heat up until it can successfully start to heat the water.

Experiment 3

AIM
To discover the effect of heat on a quantity of water.

APPARATUS
* a measuring cylinder
* a thermometer - vela, sense and control
* a metal pan
* stop watch

ALTERATIONS
Given that 500ml is to be used to do the experiment. This amount of water was tested for 7 minutes only resulting in very minor changes in the temperature.

PROCEDURE
- 50 ml of hot tap water is collected in a measuring cylinder
- The temperature of the water is measured
- The hot water is poured into a metal pan
- The immersion heater is placed in the hot water and is switched on
- The temperature is recorded every 20 seconds for ten minutes
- The immersion heater is switched off and the temperature is continued to be recorded for a further 5 minutes
- The water is poured back into the measuring cylinder and the amount of water left is measured
- The results have been plotted on a graph

RESULTS

Amount of water used = 50 ml

Temp. of water at the start = 26 °C

Time in sec	Temperature in °C
20	28
40	29.3
60	31.1
80	32.5
100	34.7
120	36.9
140	39.2
160	41.4
180	43.7
200	46.2
220	48.6
240	50.9
260	53.3
280	55.6
300	57.9
320	60.2
340	62.3
360	64.3
380	66.2
400	68.1
420	70.1
440	71.9
460	73.6
480	75.2
500	77.3
520	80.6
540	82.5
560	83.5
580	84.7
600	86

At this point the immersion heater was switched off and the temperature recorded for a further 5 minutes.

620	87.4
640	88.2
660	88.2
680	88
700	87.3
720	86.3
740	85.4
760	84.5
780	83.5
800	82.6
820	81.5
840	80.3
860	79.4
880	78.2
900	77.1

At the end, amount of water left = 51 ml

Experiment 4

AIM

To discover the effect of the same amount of heat on different masses of water.

APPARATUS

This experiment uses the same apparatus used in the previous experiment; experiment 3. The only change which is needed to be made is that the amount of water used has either got to be decreased or increased.

PROCEDURE

The procedure carried out here is the very same to the one for experiment 3, only here 60 ml of hot tap water is used instead of 50 ml.

The experiment is kept fair by using the same container in both experiments, to keep the size, shape, material and volume of the container constant. The same amount of energy is also used in both experiments.

RESULTS

Amount of water used = 60 ml

Temp. of water at the start = 25°C

Time in sec.	Temperature in °C
20	26.1
40	28.3
60	29.6
80	31.8
100	34.3
120	36.7
140	39.1
160	41.3
180	43.6
200	46
220	48.3
240	50.5
260	52.8
280	55.2
300	57.4
320	59.6
340	61.7
360	63.8
380	65.7
400	67.5
420	69.4
440	71.5
460	73.3
480	75
500	76.7
520	79.7
540	81.3
560	82.7
580	83.5
600	85.3

At this point the immersion heater was switched off and the temperature recorded for a further 5 minutes

620	86.7
640	87.8
660	87.7
680	87.2
700	86.6
720	85.9
740	85.2
760	84.5
780	83.8
800	83
820	82.2
840	81.3
860	80.5
880	79.7
900	78.9

At the end, amount of water left = 61 ml

COMPARING EXPERIMENTS 3 AND 4

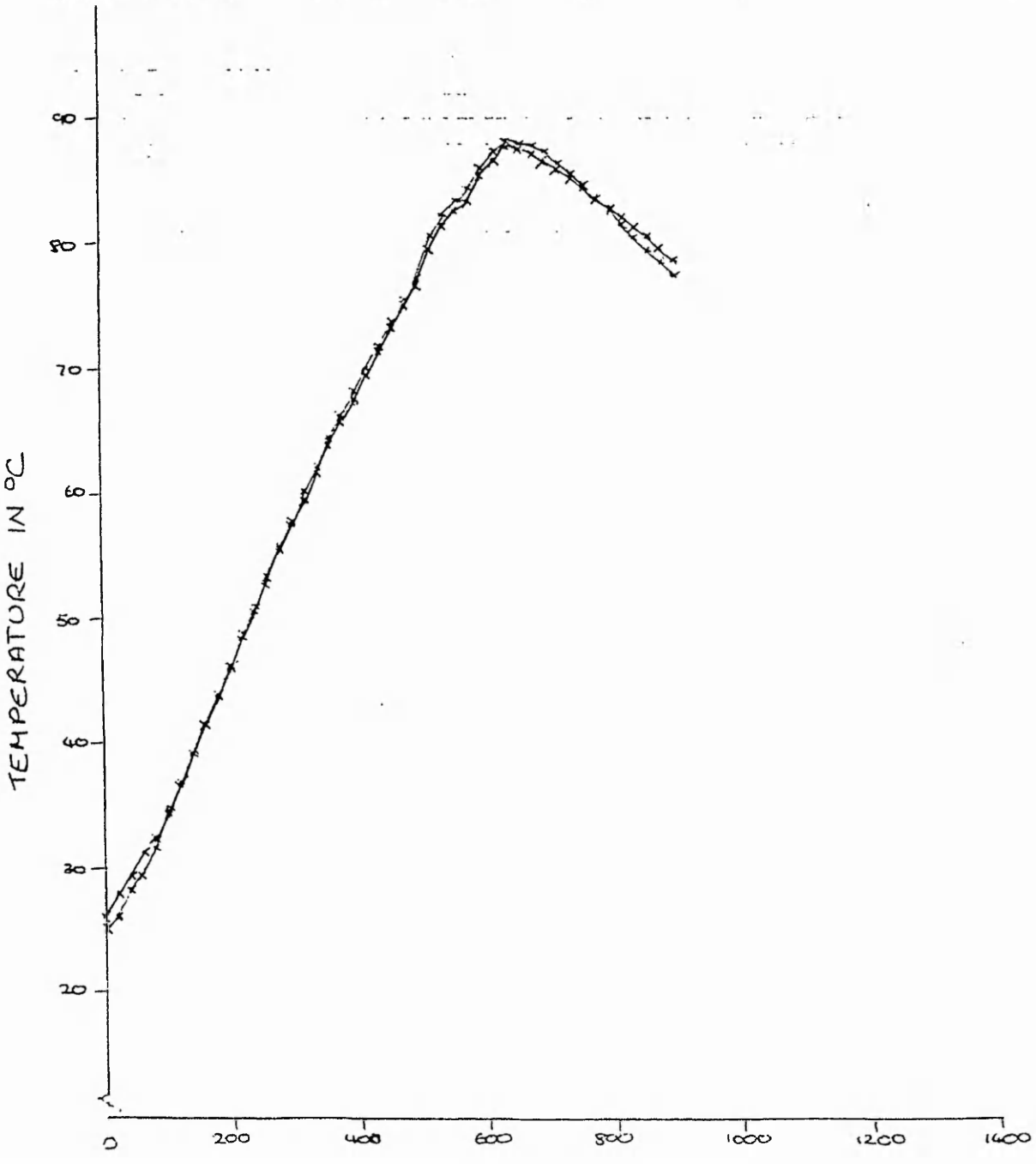
At the end of both the experiment the amounts of water had increased by 1 ml, this is because the heat energy has caused the water to expand, as the water from both experiments was left to cool, the volume (amount of water) decreased - back to it's volume.

Also it can be seen in the graph on the next page that both the experiments had fairly the same speed as they began to rise in temperature. As the water from the experiments stared to cool there was a difference in the pattern. The experiment done with the less amount of water stated to cool more quickly.

THIS GRAPH IS TO SHOW THE RISE IN TEMPERATURES, COMPARING EXPERIMENT 3 WITH EXPERIMENT 4

Key

The red line represents experiment 3 - 50 ml of water
The blue line represents experiment 4 - 60 ml of water



Experiment 5

AIM

To discover the effect of the same amount of heat on the same masses of different substances.

APPARATUS

* some metal blocks
* immersion heater
* thermometer
* power supply.
* oil

PROCEDURE

- Each block weighs 1 kilogramme
- The immersion heater and thermometer are inserted in the appropriate holes in the metal block (a little oil should be in the hole for the thermometer to ensure it makes good contact with the block)
- The heater is connected and switched on for 5 minutes
- The temperature will rise for some time after the heater is switched off; the highest temperature reached is recorded
- The experiment is repeated with blocks of other materials

RESULTS

The temperature has been recorded every 30 seconds.

The Aluminium Block

Time in sec.	Temperature in°C
30	31
60	33
90	34
120	35
150	35
180	36
210	37
240	38
270	39
300	40
330	40
360	40
390	40
420	40

The highest temperature reached in this experiment is 40°C

The Steel Block

Time in sec.	Temperature in°C
30	35
60	37
90	39
120	41
150	42
180	45
210	47
240	49
270	50
300	52
330	52
360	52
390	52
420	52

The highest temperature reached in this experiment is 52°C

The Copper Block

Time in sec.	Temperature in°C
30	32
60	36
90	39
120	40
150	42
180	45
210	45
240	47
270	49
300	50
330	51
360	51
390	51
420	51

The highest temperature reached in this experiment is 51°C

The Brass Block

Time in sec.	Temperature in°C	Time in sec.	Temperature in°C
30	29	240	44
60	31	270	46
90	33	300	48
120	35	330	49
150	37	360	49
180	40	390	49
210	42	420	49

The highest temperature reached in this experiment is 49°C

CONCLUSION

The results obtained from the experiments show that:
Aluminium heats the slowest and Steel the fastest forming this order.

Steel - the fastest
Copper
Brass
Aluminium - the slowest

The heating of the water has a lot to do with the container that it is in at the time of heating. The faster the container heats the faster the water heats, if the container takes a long time to heat then so will the water in it. So using Steel as a container to heat the water in, would be a good idea to speed up the process, but this could also mean that the steel container could get very hot.

THE VISIT TO HICKINGS

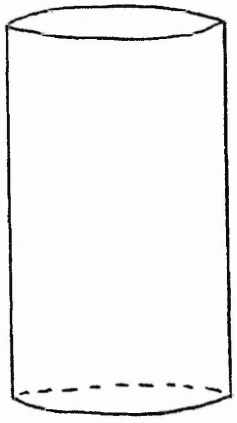
On the 7th July 1993, a group of four of us; who were working on the investigation, were given the opportunity to visit the Hickings Dying Industry in Nottingham. There, we were greeted by both Mr. Folman; the Managing Director, and Mr. Bennett the Dye House Manager. We later sat down to carry out an interview with Mr. Bennett. He helped us by answering our questions on how the industry is run and how daily routines are organised and carried out.

We were given the chance to be taken on a guided tour around the factory and to witness the different stages the fabrics go through before they are actually packaged for despatching.

To help us with our study, a tank with the capacity of 181 litres had been set aside for us to carry out a few of our own experiments. The use of this container to the factory is to dissolve chemicals. Measurements of this tank were taken to record different volumes with different levels of water. Variables such as time and temperature were also measured so that they could be compared. The following are the measurements taken at the Hickings factory:

TANK
====

$\pi r^2 h$



C = 1.86 m
D = 62 cm r = 30.5 cm
=>0.305 m
h = 62 cm

Total volume = 0.18 m3
= 181 litres

The temperature of the steam was found out to be 340°F
= 171°C

FACTS ABOUT THE TANK AT HICKINGS

After taking all the measurements of the tank during the visit these are the results:

- The temperature of the water when it comes out of the tap = 19.5°C.
- The temperature of the steam when it comes out of the tap = 171°C.
- The tank has a capacity of . . . . = 181°C.
- The temperature needed to be reached = 60°C.
- The internal diameter of the steam pipe = 14 mm

RESULTS TO EXPERIMENTS CARRIED OUT AT HICKINGS

Experiment 1

PROCEDURE

The water tap was opened to fill the tank to a level of 30 cm. This was done by lowering a measured and marked, narrow plank of wood into the tank whilst it was being filled with water. The plank is then removed to take the temperature of the water which is 19.5°C. Then the steam is turned on and the temperature of the water is measured every 20 seconds until the water reaches the temperature needed which is 60°C.

RESULTS

Level of water = 30 cm

$\therefore$ the volume of water in the tank = $\pi r^2 h$
= $\pi \times (0.305 \times 0.305) \times 0.3$
= 0.087 m3
= 87.7 litres

Time in sec.	Temperature in °C
20	25.6
40	32.4
60	38.4
80	45
100	51.2
120	57.4
130	60

With 87.7 litres, time taken to reach 60°C = 2 min 10 sec
Level of water at the end of the experiment = 34 cm
= $\pi \times (0.305 \times 0.305) \times 0.34$
= 0.099 m3
= 99 litres

Experiment 2

PROCEDURE

The procedure to this experiment is the same to experiment 1, the only change is in the level/volume of water.

RESULTS

Level of water = 36 cm

$\therefore$ the volume of water in the tank = $\pi r^2 h$

$= \pi \times (0.305 \times 0.305) \times 0.36$

$= 0.105$ m3

$= 105$ litres

Time taken for the tank to fill to 36 cm/105 litres = 20 seconds

With 105 litres, time taken to reach 50°C = 2 min 5 sec

Level of water at the end of the experiment = 38 cm

$= \pi \times (0.305 \times 0.305) \times 0.38$

$= 0.111$ m3

$= 111$ litres

Experiment 3

PROCEDURE

The procedure for this experiment is also the same as the first two. Again the only difference is that of the change in the level/volume of the water.

RESULTS

Level of water = 42 cm

∴ the volume of water in the tank = $\pi r^2 h$
= $\pi \times (0.305 \times 0.305) \times 0.42$
= 0.122 m3
= 122.7 litres

Time taken for the tank to fill to 42 cm/122.7 litres = 58 seconds
With 122.7 litres, time taken to reach 50°C = 2 min 34 sec
Level of water at the end of the experiment = 45 cm
= $\pi \times (0.305 \times 0.305) \times 0.45$
= 0.131 m3
= 131.5 litres

CONCLUSION

These results show that the higher the amount of water in the tank, the longer it takes to fill and the longer it takes to reach the destined temperature.

APPROACHING THE PROBLEM

What is the best way of heating water?

If water is to be heated, as for anything, a source of energy is needed. The energy needed here is HEAT. This energy can be received by the one and only natural source - the SUN.

Nowadays, to make life easier for us technology has made it possible for sources such as the following, be put to common everyday use. These sources are:

* Gas
* Electricity
* Steam

These sound simple enough but there are a lot of points to think about whilst putting these sources of energy to use. There are many things to consider before actually being able to use these sources economically. Any of these sources can be used, but the results obtained will depend on the following:

- Amount of water used
- Amount of energy used
- Change in temperature
- Time taken

We have decided to approach the problem by first thinking about the factors which are involved and those which rotate around the actual subject. The following have to be taken into consideration:

- Resources
- Quickness in time
- Cheaper in cost
- Simplest for use
- Supports environmental issues.

Keeping all these factors in mind we are going to design investigations to find a possibe solution to the problem.

INVESTIGATION 1

HYPOTHESIS

I intend to heat an amount of water up to 60°C in a Water Bath. To measure the variables accurately I will have to use a digital thermometer to measure the temperature at regular intervals until the wanted temperture is reached.

Using ratios I could get reliable data eg. by doing the experiment for ¼ the amount of water used at Hickings and then by predicting the answer for ½ the amount of water, then doing the experiment for ½ the amount of water would be proof that the predictions are reliable and can be used to be compared to results of predictions for other experiments. The calculation I have used in this experiment to scale down the amount of water is as follows:

Approximate capacity of the tank at Hickings ≈ 180 litres
= 180 ÷ 15 = 12 litres
= 12 ÷ 2 = 6 litres

I think that the amount of water put in does depend on how fast or how slow the water heats. I would say that this 6 litres of water would take ≈ 20 miutes to heat to 60°C in the Water Bath. I also think that it will stay at this temperature for ≈ 2 hours.

INVESTIGATION 1

APPARATUS

* Water Bath
* Digital Thermometer
* Digital Ammeter
* 6 litres of water
* Measuring Cylinder
* Stop watch

PROCEDURE

- Measure 6 litres of water at the temperature of 19.5°C and fill the Water Bath.
- Attach the water bath to the digital ammeter
- Switch on the water bath and set it to 60°C
- Start the stopwatch and record the temperature every minute until it reaches 60°C
- record all the tempertaures.

RESULTS

Starting tempertaure = 19.5°C

Time in minutes	Temperture in °C
1	20.9
2	22.8
3	24.5
4	26.4
5	29.1
6	31.7
7	33.5
8	36
9	38.6
10	40.2
11	43
12	45.1
13	46.9
14	49.1
15	51.2
16	53.2
17	55.1
18	56.6
19	57.4
20	58
21	58.2
22	59
22.26	60

Energy used = 4.04 A

CONCLUSION

The water bath bears an indication of it's power which is 1000 W. This power can also be calculated by using the following formula:

Power = Voltage × Electric Current
P = V × I
P = 240V × 4.04A
P = 969.6 W
∴ P ≈ 1000 W

The amount of energy supplied can be calculated by using the following formula:

Energy = Power × Time
E = P × t
E = 1000 × 22 min 26 sec
=> 22 minutes × 60 = 1320 seconds
=> 1320 seconds + 26 seconds = 1346 seconds
E = 1000 × 1346 seconds
∴ E = 1346000 J
∴ E = 1346 KJ
∴ E = 1.346 MJ for 6 litres of water

6 l = 1.346 MJ
1 l = 0.224 MJ
100 cm3 = 0.022 MJ
750 cm3 = 0.168 MJ

The amount of energy used here has been scaled down for an amount of 750 cm3 because the other two investigations to follow were done with 750 cm3 because they could not possibly have been done with 6 litres of water in the school laboratories.

My predictions for this experiment were quite near the actual answers. I had predicted that it would take ≈ 20 minutes for the water to heat to 60°C and the water took exactly 22 minutes 26 seconds to heat.

This experiment is quite efficient because it automatically switches itself off as soon as it reaches 60°C, by this no electricity is wasted.

INVESTIGATION 2

HYPOTHESIS

I intend on heating 750 cm3 of water to 60°C using gas. I will need to use a gas flow meter to measure the flow of gas in litres. A thermometer to measure the temperature. A computer to give me more accurate information including how much energy is being used up. Also the computer indicates how long it is going to take for water to heat to 60°C.

After doing the experiment using electricity and obtaining results I have predicated how much energy this experiment will use up.

I think that more energy will be used in gas than in electricity, becaues in electricity all the energy is kept in and used within. In gas a lot of the heat is let off into the air from the Bunsen burner. Some of the energy will be given out instead of being kept in and being used. Using the equation -

$$\text{Power} = \frac{\text{Work Done}}{\text{Time Taken}}$$

it has been calculated that 0.168 MJ is used for heating 750 cm3 when using electricity. I have predicted that the energy used in the investigation with gas will be double the amount used in electricity.

Predictions - 750 cm3 will use ≈ 0.337 MJ

On the other hand I think that this experiment will be much quicker than the one done with electricity because the flow of gas will be much faster.

INVESTIGATION 2

APPARATUS

* Gas Flow Meter
* Digital Thermometer
* Computer
* Container (to hold the water)
* Bunsen Burner
* 750 cm3 of Water

PROCEDURE

- Attach the gas flow meter to the computer and the Bunsen burner which should be connected to a gas supply
- The Bunsen burner and the computer are switched on at the same time
- All the apparatus is left on until the water reaches 60°C
- As soon as the temperature is reached, both the computer and the gas supply are turned off
- All the information needed and obtainable can be seen on the screen of the computer and the little digital screen on the gas flow meter
- All the information is recorded

RESULTS

The following results have been obtained from heating 750 cm3 of water with gas. The results have been taken after reaching the destined temperature of 60°C.

Total Volume = 10.5 litres
Flow Rate = 82.7 litres
Total Energy = 0.4000 MJ
Total Cost = 0.1687p
Time = 6 minutes 36 seconds

CONCLUSION

According to my prediction the amount of energy used in this experiment was to be double the amount used in the previous investigation which was 0.168 MJ and the predicted amount for this experiment was double that = 0.336 MJ.

The results for this experiment show that the amount of energy used to heat 750 cm3 of water is exactly 0.4000 MJ.

This figure is very near to the one which had been predicted. The results followed the pattern that I thought was taking place, ie. that the amount of energy used will increase (≈ by double) because the same amount of energy or even more is lost in the air instead of all of it being used - when using gas.

Using gas does not take a long time but quite a lot of perfectly good resources are being wasted.

INVESTIGATION 3

HYPOTHESIS

I intend on heating 750 cm3 of water to 60°C using steam. This is a similar method to the one actually used at Hickings at the moment.

In this experiment I will need a Steam Producer to produce the steam from the water, again I will need a digital thermometer to give accurate measurements of the temperature at regular intervals. I will need a stop watch to time how long it takes for the water to reach that temperature and a container to hold the water will also be needed.

I could predict that, from the results obtained by the experiments carried out at Hickings, that the water will take but a number of seconds for the water to reach that temperature, but if I do say this I would be making a mistake because the steam pipe at Hickings is much wider in internal diameter than the one which is present at school. Also the material of the steam pipes differ as the one at Hickings is one metal but the one at school is made from rubber.

I would say that with the equipment at school the water will take ≈ 5 minutes to reach 60°C when using steam.

This experiment would be so quick because the steam is already very hot when it reaches the water not needing any more time to heat itself up before it starts heating the water, but can immediately start doing so.

INVESTIGATION 3

APPARATUS

* Steam Producer
* Digital Thermometer
* 750 cm3 Water
* Container for the Water
* Stopwatch

PROCEDURE

- Get the Steam Producer working by filling it with water and heating it
- Put the water into the container and take it's temperature
- Put the steam pipe into the water, along with the thermometer
- Start the stopwatch
- keep taking the temperature every 30 seconds
- Stop the stopwatch as soon as the water reaches 60°C
-

RESULTS

Temperature of the water, at the start of the experiment = 19.5°C

Time in sec	Temperature in °C
30	24
60	30.9
90	32.9
120	35.6
150	40.2
180	44.6
210	48.3
240	52.6
270	56.9
295	60

Time taken to reach 60°C = 4 minutes 55 seconds
Energy used in 1 minute = 2.2 litres of gas

From this it can be worked out, how much energy was used for the whole process.

Gas used in 1 minute = 2.2 litres
∴ gas used in 1 second = 2.2 litres ÷ 60 = 0.037
gas used in 295 seconds = 0.037 × 295 = 10.9 litres

CONCLUSION

My prediction of this experiment taking 5 minutes to reach 60°C was very close to the actual answer, which is 4 minutes 55 seconds. This experiment may be quick but it also wastes quite a lot of resources which can be used.

FINAL CONCLUSION

This is a list of the amounts of energy which will be needed to heat 180 litres to 60°C:

Using electricity = 1.346(for 61) × 2 = 2.692 MJ
for 180 litres = 2.692 × 15 = 40.38 MJ

Using gas = 0.4000 MJ(for 750cm3) ÷ 7.5 = 0.0533 MJ
= 0.0533 × 10 = 0.533 MJ
= 0.533 × 6 = 3.198 MJ
= 3.198 × 2 = 6.396 MJ
for 180 litres = 6.369 × 15 = 95.94 MJ

Using steam = 0.415 MJ(for 750cm3) ÷ 7.5 = 0.0553 MJ
= 0.0553 × 10 = 0.553 MJ
= 0.553 × 6 = 3.32 MJ
= 3.32 × 2 = 6.64 MJ
for 180 litres = 6.64 × 15 = 99.6 MJ

∴ Using electricity = 40.38 MJ
Using gas = 95.94 MJ
Using steam = 99.60 MJ

This shows that the process with <u>electricity</u> needs the least amount of energy to be carried out, then there is gas and then the steam.

The following is a list of the times taken for the experiments to reach 60°C:

Using electricity = 22 minutes 26 seconds
Using gas = 6 minutes 36 seconds
Using steam = 4 minutes 55 seconds

This shows that the process with <u>steam</u> heats to 60°C the quickest.

The following is a list in order of efficiency or the simplest for use:

Using electricity = This can be switched on and left, as it will turn itself off when it reaches the set temperature.
Using gas = This has to be constantly watched and then switched off manually after the wanted temperature is reached.
Using steam = This is similar to the gas as it follows the same process of burning, again the equipment has to be turned off manually after the wanted temperature is reached.

This shows that the process with <u>electricity</u> is the most efficient.

FINAL CONCLUSION

The following is a list of how the experiments support environmental issues:

Using electricity = All the energy used here is kept within and all of it is used without wasting anything.

Using gas = A lot of energy is wasted here as a great deal of the gas released from the Bunsen burner is let off into the air, this is unavoidable, unless of course if a piece of equipment is made as though the heat can be transfered from the burner sraight into the water or at least the container without the flow being cut anywhere in between.

Using steam = This is similar to the gas because again energy is lost on the way. In this, there is another disadvantage ie. when the steam reaches the water it is again exposed to the air and more energy is lost in the process.

This shows that the process with <u>electricity</u> is the most environmentally friendly.

From all of this a final conclusion can not be drawn! It all depends on personal choice.
Electricity does seem a good idea as is environmentally friendly, very efficient, economical and automatic but it is also very expensive when used on a large scale. The other disadvantage is that it takes a long time to heat the water.
Gas seems a practical way of using resources as it is quick and not very expensive, but it has to be taken into consideration that a lot of energy is lost in this process so the fact that gas does not cost a lot could be made up by the fact that it uses much more energy hereby increasing the total price.
Steam looks very much on the same situation as a lot of energy is released into the air instead of being used.

It is up to the person in charge to choose because some authorities would have the time to use electricity and less of manual workers, whereas others may have little time and more manual workers to use resources such as gas and steam.

Each of the methods have certain advantages and disadvantages, some more than others! It's up to you to choose...

Section 3 - Pupil questionnaire response analyses: all learning styles for year 10 pupils

CLASS 10 4 Summary of all learning styles

class 10.4	SC total/s.d.	OE total/s.d.	PS1 total/s.d.	RC total/s.d.	PS2 total/s.d.
a	25/1.59	22/1.25	24.5/1.16	22/0.99	19/0.7
b	18.5/1.22	18.5/1.6	29.5/1.41	31.5/1.1	27/1.36
c	12/0.88	28/2.33	33/1.58	17/2.26	19/1.91
d	14.5/1.15	23/0.65	29.5/1.41	21/1.41	16.5/0.95
e	16/0.7	225/1.25	22/1.25	19/1.83	16/0.88
f	26/1.48	29/1.2	29/1.36	27.5/0.84	25.5/0.64

CLASS 10 XA Summary of all learning styles

10xa	SC total/s.d.	OE total/s.d.	PS1 total/s.d	RC total/s.d	PS2 total/s.d
a	21/1.07	28/1.07	21/1.31	15.5/0.75	21/1.41
b	15/1.12	38/0.9	28/1.85	15/1.55	24/1.76
c	19/1.03	23/1.16	21/0.93	21/0.76	20/0.64
d	22/0.83	27/1.12	23/1.39	20/0.83	22/0.99
e	19/1.48	34/1.25	25/1.76	14.5/1.32	27.5/1.21
f	25/1.68	37/1.75	29/1.25	11/0.9	18/2.19
g	15/1.25	36/1.12	28/1.51	26/1.39	34/1.12
h	10/0.73	35/1.77	33/1.75	15/1.55	30/1.75
i	12/0.7	31/1.59	24/2.26	11/0.73	25/1.18
j	13/1.12	33/1.75	30/2.05	18/1.92	27/1.64
k	16/1.48	29/1.81	31/1.59	11/1.05	31/1.59
l	21/1.07	27/0.64	24/1.59	16/1.16	20/1.12
m	12/1.16	31/1.59	31/1.76	11/1.40	15/1.88
n	14/1.31	32/1.18	29/1.64	19/1.75	22/0.99
o	14/0.53	26/1.28	27/1.12	14/1.20	20/0.64
p	20/1.36	26/1.28	23/1.16	13/0.99	20/1.12
q	22/1.25	31/0.9	28/1.77	16/1.48	22/0.99

CLASS 10 XB Summary of all learning styles

10XB	SC total/s.d.	OE total/s.d.	PS1 total/s.d.	RC total/s.d.	PS2 total/s.d.
a	11/0.73	26/1.58	28/1.31	11/0.73	27/1.36
b	29/1.64	32.5/1.33	39/1.03	16.5/1.62	35.5/0.94
c	20/1.25	27/1.73	27/1.46	11/0.73	18/0.73
d	13/1.36	32/1.68	31/1.50	17/1.84	24/1.18
e	10/0.49	29/1.46	31/1.68	25/1.76	28/1.31
f	21/1.31	35/1.77	21/2.14	11/1.05	25/1,05
g	20/1.36	35/1.77	22/2.10	11/1.05	25/1.05
h	19/1.39	30/2.19	22/2.10	11/1.05	25/1.05
i	19/0.7	22/0.99	22/0.64	17/0.73	23/0.88
j	20/0.99	25/0.73	22.5/0.84	19/0.45	22.5/0.65
k	15/0.83	25/0.9	25/1.59	17/1.19	19/0.87
l	17/1.50	23/1.39	19/1.28	15/1.12	18.5/0.79
m	18/1.05	28/1.20	24/1.29	18/1.05	23/1.28
n	10/0.73	29/1.25	25/1.5	14/1.31	19/1.39
o	10/0.73	29/1.25	25/1.76	20/1.73	18/1.48
p	21/1.07	26/0.7	23/0.45	20/1.12	22/0.64
q	12/1.16	20/1.64	23/1.91	11/1.05	16/1.67
r	11/0.73	30/1.58	25/1.68	15/1.12	19/1.16
s	20/1.55	28/1.60	23/1.83	22/1.73	18/0.73

CLASS 10XC Summary of all learning styles

pupil	SC total/s.d.	OE total/s.d.	PS1 total/s.d	RC total/s.d	PS2 total/s.d
a	25/1.59	35/1.41	33.5/1.77	22/1.81	37/1.16
b	25/1.5	33/1.28	29/1.55	29/1.25	32/1.18
c	28/0.76	32/1.68	28/1.6	21/1.07	23/1.16
d	29/0.99	29/1.36	24/1.50	26/0.7	30/0.88
e	25/1.59	30/1.48	28/1.31	16/1.48	27/1.45
f	19/1.03	27/0.83	29/1.46	17/0.73	26/0.65
g	17/1.40	36/1.12	29.5/1.92	20/1.81	27/2.03
h	19/1.91	32/1.29	30/1.16	20/1.88	22/1.25
i	28/1.69	32/1.50	29/1.25	25/1.18	31/1.50
j	25/0.49	25/0.73	26/0.45	26/0.45	28/0.00
k	26/1.16	23/0.45	24/0.73	24/1.05	28/0.76
m	28/0.93	25/0.73	28/0.93	24/0.73	30/0.70
n	31/1.18	15/1.25	18/1.92	27/0.99	16/0.88
o	24/1.59	27/1.22	26/1.03	14/1.07	17/0.73
p	17/0.49	31.5/1.22	27/0.64	17/1.40	21/1.07
q	14/0.93	32/1.18	24/1.68	18/1.29	19/1.03

CLASS 10YA summary of all learning styles

YA					
a	24/0.73	31/1.59	22.5/1.89	12/0.7	22/0.83
b	16/1.83	30/1.58	31/1.68	9/0.45	23/1.16
c	20/1.64	21/1.31	27/0.83	20/1.81	23/1.16
d	22/2.10	25/1.68	29/2.17	24.5/1.63	20.5/1.9
e	24/0.49	26/1.16	27.5/1.94	8/0.35	24/1.5
f	17/1.05	18/1.76	30/1.75	16/1.28	30/1.75
g	10/0.49	29/1.73	31/1.59	21/1.85	29/1.36
h	14/0.93	33/1.03	27/1.64	18.5/1.53	31/1.29
i	8/0.35	31/1.59	33/1.58	15.5/0.75	24/1.40
j	15/1.73	25/1.4	24/2.06	7/0.0	12/0.45
k	14/1.69	24/1.18	21/1.51	15/1.88	12/0.45
l	17/0.9	25/1.4	30/1.67	13/1.73	21/1.31
m	12/0.7	30/1.28	28/1.07	12/0.7	16/1.03
n	21/0.76	27/1.55	23.5/1.16	10/0.73	24/0.73
o	18/1.05	35.5/0.94	26/1.98	21/1.07	16/1.48
p	21/0.93	29/1.12	25/1.76	13/0.64	18/1.50
q	18/1.18	17/1.76	30/1.75	19/1.67	27/2.10

CLASS 10YD Summary of all learning styles

10YD	SC total/s.d.	OE total/s.d.	PS1 total/s.d.	RC total/s.d.	PS2 total/s.d.
a	12/1.75	22/2.5	22/2.5	17/2.2	17/2.26
b	22/0.6	30/1.6	27/1.22	14/1.07	31/1.3
c	21/0.8	28/1.69	30/1.28	18/0.7	31/1.3
d	23/1.39	27/1.25	24/1.5	28/0.53	25/1.4
e	20/2.1	29/0.8	31.5/1.1	24/1.2	29.5/0.75
f	24/1.3	30/1.67	27/2.5	22/1.2	16/1.3
g	20/1.25	27/2.1	25/2.3	18/1.84	14/1.07
h	16/1.16	21/0.5	24/1.18	20/1.8	17/0.5
i	14/1.2	30/1.4	26/1.28	19/1.83	20/1.0

CLASS 10YB Summary of all learning styles

10YB	SC total/s.d.	OE total/s.d.	PS1 total/s.d	RC total/s.d	PS2 total/s.d
a	11/0.73	16/1.03	21/1.31	16/0.88	25/1.5
b	19/1.48	27.5/1.7	31/1.59	23.5/1.03	30/1.39
c	19/1.39	27/1.55	29/1.12	18/1.68	18.5/1.33
d	23/1.36	24/1.18	19/0.65	20/1.12	19/0.7
e	20/1.36	23/1.28	29/0.83	19/0.7	23/0.7
f	17/1.4	2/1.12	34/1.36	22/0.99	27/1.55
g	18/1.68	24/1.18	34/1.36	22/0.83	21/1.2
h	17/1.05	28/1.69	35/1.41	20/1.64	26/1.91
i	21.5/1.08	22/0.83	29/1.46	17/1.40	26/0.45
j	22/0.99	33/1.28	32.5/1.22	24.5/0.46	32/0.9
k	7/0.00	26/1.16	30/1.58	18/1.99	16/1.16
m	12/0.7	30/1.56	20/2.10	17/1.18	12/0.88
n	14/0.76	28/1.51	265./1.36	21/1.20	17/0.9
o	14/1.31	32/0.9	24/1.59	21/1.2	22.5/0.99
p	18/1.29	29/0.99	29/1.96	22/1.64	18/0.73
q	17/1.29	26/1.28	27.5/1.08	18.5/0.58	15/0.64
r	21/0.93	26/1.67	26/1.67	20/2.03	26/1.75

CLASS 10YC Summary of all learning styles

10YC	SC total/s.d.	OE total/s.d.	PS1 total/s.d.	RC total/s.d.	PS2 total/s.d.
a	15/0.64	31/0.73	26/1.16	18/1.05	25/0.73
b	165./0.79	29.5/0.75	27.5/0.94	20.5/0.8	25/0.69
c	14.5/1.24	27/0.87	27/0.84	24.5/1.3	22/0.87
d	20/1.64	26/1.39	23/1.48	25/1.5	27/1.12
e	19/1.28	23/1.16	21/1.51	26/1.48	25/0.49
f	23/0.45	23/0.45	23/0.45	23/0.45	21/0.17
g	25.5/1.12	34.5/1.82	26/1.67	14/1.4	25/1.58
h	23/1.48	32/1.29	23/1.91	19/1.75	24/0.9
i	23/1.16	24/1.18	31/1.4	27/1.73	23/1.7
j	28/1.6	31.5/1.49	26/1.6	16/0.9	27/1.16
k	24/1.76	42/0.0	30/1.7	11/0.73	24/1.6
l	26/1.28	38/1.40	30/1.83	11/0.7	24/1.6
m	23/0.52	24.5/0.0	24.5/0.0	24.5/0.0	24.5/0.0
n	20/1.25	35/1.31	28/1.77	8/0.35	36/1.12
o	12/0.70	22/1.12	25/2.06	16/1.8	25/0.9

CLASS 10YE summary of all learning styles

10YE					
a	22/1.96	22/1.25	27/1.55	22/1.64	18.5/0.79
b	21.5/1.08	28/1.77	26.5/1.25	22.5/1.22	20/1.55
c	25.5/1.03	31.5/1.79	36.5/0.99	14.5/1.82	29.5/0.75
d	17/2.26	24.5/2.31	24.5/2.31	14.5/1.82	27/2.08
e	26/1.67	20/1.81	25/1.76	19.5/1.69	22.5/1.81
f	18/1.59	22/0.64	25/1.59	18/1.76	13/0.64

All classes summary of learning styles

m = mean
s = standard deviation

class	SC m/s	CE m/s	PS1 m/s	RC m/s	PS2 m/s
10XC	23.4/4.88	29.3/5.128	27.3/3.048	29.6/4.12	25.6/5.946
10XB	16.6/5.142	27.97/3.98	25.1/4.639	15.86/4.14	22.39/4.59
10XA	17.146/4.167	30.33/4.568	26.4/3.99	15.7/3.968	23.4/4.819
10YE	21.7/3.166	24.7/3.74	27.4/4.625	18.5/3.202	21.75/5.45
10YD	19.1/3.982	27.1/3.305	26.3/2.625	19.9/3.928	19.4/6.455
10YC	20.8/4.656	29.5/6.0	26/3.38	18.9/5.89	25/4.123
10YB	17/4.513	26.5/3.903	28/4.867	19.97/2.328	22/5.398
10YA	17.1/4.56	26.85/4.896	27.38/3.276	14.9/5.159	21.9/5.59
MEANS FOR ALL GROUPS	19.06/2.26	27.3/2.47	26.86/1.035	18.7/2.638	22.44/1.84

Section 4 - Pupil questionnaire response analyses:
social cohesiveness style for year 10 and year 12 pupils

Class 6th form (year 12) Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
1	4	2	2	2	1	2
1	3	2	2	1	2	1
1	4	2	1	2	1	1
1	2	2	1	2	1	1
1	1	2	1	2	1	2
1	1	5	1	3	1	1
total = 6	15	15	8	12	7	8
mean of totals = 10						
dev'n = -4	5	5	-2	2	-3	-2
mean 1.00	2.50	2.67	1.33	2.00	1.17	1.33
s.d. 0.00	1.26	1.11	0.47	0.58	0.37	0.47

mean of means = 1.714
s.d. of means = 0.608

Class 10 KR Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
1	3	3	1	6	1	1
1	2	4	2	3	1	1
1	1	2	1	1	1	2
1	4	4	3	3	1	1 test case
1	2	2	4	3	1	1
1	1	3	1	3	1	3
1	1	1	3	1	1	2
1	1	2	2	1	1	3
1	3	3	2	2	2	1
1	1	2	1	2	1	2
2	1	3	1	2	1	3
1	1	5	1	4	1	2
1	1	2	1	2	1	2
1	2	5	1	3	1	2
1	1	3	2	4	2	3
2	2	2	2	3	2	1
2	2	5	2	5	2	3
3	5	4	4	4	1	1
1	4	3	2	2	1	2
1	4	3	2	2	5	2
1	1	3	1	2	1	2
1	5	2	1	1	1	2
TOTAL 27	48	66	40	59	30	40
MEAN OF TOTALS = 46						
DEV'N=-19	2	20	-6	13	-16	-6
MEAN 1.23	2.18	3.00	1.82	2.68	1.36	1.91
S.D. 0.52	1.37	1.09	0.94	1.29	0.88	0.73

MEAN OF MEANS = 2.026
S.D. OF MEANS = 0.974

Class 10XA Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
1	5	2	6	4	3	4
1	4	1	2	3	4	3
1	1	3	1	3	1	2
1	2	2	1	1	4	4
2	1	3	2	3	3	2
3	1	6	3	4	4	5
4	4	3	4	2	1	3
3	4	1	3	1	1	2
2	2	3	2	3	5	2
2	3	4	3	4	4	2
1	5	2	4	4	1	2
1	5	5	5	4	4	1
1	5	2	2	2	1	2
1	2	1	3	1	1	1
1	3	2	2	2	1	1
1	3	1	4	2	1	1
1	2	2	3	5	1	1
2	3	2	4	2	5	3
1	1	3	1	1	4	1
2	2	1	1	1	5	2
2	2	2	2	3	1	2
2	4	4	4	4	1	1
2	4	3	4	3	1	5
2	6	3	2	2	2	2
TOTAL 40	74	61	68	64	59	54
MEAN OF TOTALS =		60				
DEV'N =20	14	1	8	4	-1	-6
MEAN 1.67	3.08	2.54	2.83	2.67	2.46	2.25
S.D. 0.80	1.47	1.26	1.31	1.18	1.58	1.20
MEAN OF MEANS =		2.500				
S.D. OF MEANS =		1.257				

Class 10XB Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
0	4	2	3	2	1	2
1	2	3	1	2	1	1
1	1	4	1	3	1	1
2	4	2	2	3	5	3
1	1	2	1	3	1	1
1	1	2	1	3	1	1
2	2	1	4	3	4	2
1	5	3	3	2	1	1
2	4	2	2	2	1	2
3	5	2	2	3	3	2
3	2	2	2	3	4	3
1	3	3	4	5	1	3
1	3	3	4	5	1	3
1	3	4	4	4	1	4
1	1	1	2	2	1	2
1	1	5	2	2	1	1
2	3	5	4	3	2	1

Class 10XB Style SC (continued)

Q1	Q6	Q11	Q16	Q21	Q26	Q31
4	4	6	5	6	3	1
2	2	1	1	3	1	1
TOTAL 30	51	53	48	59	34	35
MEAN OF TOTALS =	44					
DEV'N =-13	7	9	4	15	-10	-9
MEAN 1.76	2.68	2.79	2.53	3.11	1.79	1.84
S.D. 0.95	1.34	1.40	1.27	1.12	1.28	0.93
MEAN OF MEANS =	2.357					
S.D. OF MEANS =	1.185					

Class 10XC Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
4	5	4	6	2	1	3
3	5	5	5	2	1	4
4	4	5	4	2	4	3
4	6	5	4	4	3	3
2	2	5	3	6	5	2
3	3	3	3	5	4	6
3	4	1	2	3	4	2
4	3	1	4	1	6	1
3	3	5	3	1	1	1
1	2	1	5	3	6	1
4	6	6	3	5	1	3
2	3	4	4	3	6	4
4	2	5	3	4	6	6
4	4	5	4	5	1	1
2	2	2	3	2	3	3
2	2	2	1	4	1	2
TOTAL 49	56	59	57	52	53	45
MEAN OF TOTALS =	53					
DEV'N=-4	3	6	4	1	0	-8
MEAN 3.06	3.50	3.69	3.56	3.25	3.31	2.81
S.D. 0.95	1.37	1.69	1.17	1.48	2.02	1.55
MEAN OF MEANS		3.313				
S.D. OF MEANS		1.463				

Class YA Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
3	4	3	5	3	3	3
1	2	6	1	4	1	1
1	4	3	1	3	6	2
1	4	3	6	1	6	1
3	4	3	3	4	4	3
2	3	4	4	3	1	1
2	2	1	1	2	1	1
2	2	2	2	4	1	1
1	2	1	1	1	1	2
3	1	1	1	2	6	1

Class YA Style SC (continued)

2	1	1	1	2	6	1
2	2	2	4	3	1	3
1	2	2	3	2	1	1
3	2	2	3	3	4	4
1	3	2	2	4	4	2
3	3	3	4	3	4	1
2	4	3	4	3	1	1
TOTAL 33	45	42	46	47	51	29
MEAN OF TOTALS = 42						
DEV'N = -9	3	0	4	5	9	-13
MEAN 1.94	2.65	2.47	2.71	2.76	3.00	1.71
S.D. 0.80	1.03	1.24	1.56	0.94	2.06	0.96

MEAN OF MEANS = 2.462
S.D. OF MEANS = 1.227

Class YB Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
2	1	3	1	2	1	1
3	2	6	3	2	1	2
2	1	3	3	1	5	4
2	1	5	4	3	5	4
2	1	4	2	5	2	4
3	1	3	5	3	1	1
3	1	3	6	3	1	1
3	1	2	3	4	1	3
2	5	4	3	4	2	2
3	4	3	3	5	2	3
1	1	1	1	1	1	1
2	1	1	2	3	1	2
2	2	1	3	1	2	3
2	1	2	1	2	1	2
2	1	3	2	4	1	4
2	2	5	1	3	1	3
3	3	3	2	3	5	2
TOTAL 39	29	52	45	49	33	42
MEAN OF TOTALS = 41						
DEV'N = -2	-12	11	4	8	-8	1
MEAN 2.29	1.71	3.06	2.65	2.88	1.94	2.47
S.D. 0.57	1.18	1.39	1.37	1.23	1.47	1.09

MEAN OF MEANS = 2.429
S.D. OF MEANS = 1.186

Class YD Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
1	6	1	1	1	1	1
3	3	4	2	3	4	3
3	3	4	2	3	4	2
3	3	3	1	4	6	3
1	3	1	6	6	1	2
5	3	3	4	3	1	5
3	1	3	4	3	1	4
3	1	4	1	3	1	3
1	1	4	1	3	1	3
TOTAL 23	24	27	22	29	20	26
MEAN OF TOTALS =		24				
DEV'N = -1	0	3	-2	5	-4	2
MEAN 2.56	2.67	3.00	2.44	3.22	2.22	2.89
S.D. 1.26	1.49	1.15	1.17	1.23	1.81	1.10
MEAN OF MEANS =		2.714				
S.D. OF MEANS =		1.393				

Class YE Style SC

Q1	Q6	Q11	Q16	Q21	Q26	Q31
1	6	6	3	3	4	3
1	6	6	1	1	1	1
3	3	4	4	3	3	6
1	4	4	3	4	1	2
2	5	6	1	2	5	1
2	6	3	2	3	1	1
TOTAL 10	30	29	14	16	15	14
MEAN OF MEANS =		18				
DEV'N = -8	12	11	-4	-2	-3	-4
MEAN 1.67	5.00	4.83	2.33	2.67	2.50	2.33
S.D. 0.75	1.15	1.21	1.11	0.94	1.61	1.80
MEAN OF MEANS =		3.048				
S.D. OF MEANS =		1.223				

Whole Sample Style: social cohesiveness response standard deviations

Date	Group	Q1	Q6	Q11	Q16	Q21	Q26	Q31
27 05 94	10 XA	0.80	1.47	1.26	1.31	1.18	1.58	1.20
100594	10 XB	0.95	1 34	1.40	1.27	1.12	1.28	0.93
23 05 94	10 XC	0.97	1.37	1 .69	1.17	1.48	2.02	1.55
05 03 94	10 YA	0.80	1.03	1.24	1.56	0.94	2.06	0.96
03 05 94	10 YB	0.57	1.18	1.39	1.37	1.23	1.47	1.09
03 05 95	10 YC	1.00	1.66	1.26	1.08	1.65	0.93	1.12
03 05 94	10 YD	1.26	1.49	1.15	1.71	1.23	1.81	1.10
03 05 94	10 YE	0.75	1.15	1.21	1.11	0.94	1.61	1.80
14 12 92	10K red	0.52	1.37	1.09	0.94	1.29	0.88	0.73
14 12 92	10K Yellow	0.48	1.46	1.41	1.13	1.53	1.71	0.86
27 03 95	6th form	0.00	1.26	1.11	0.47	0.58	0.37	0.47
Mean SD		0.736	1.344	1.292	1.193	1.197	1.429	1.074

Whole sample mean SD = 1.1806

Section 5 - Pupil questionnaire response analyses:
Problem solving (PS1) style for year 10 and year 12 pupils

Gp 6th form Style PSI March 1995

Q3	Q8	Q13	Q18	Q23	Q28	Q33
1.0	4.0	3.0	3.0	6.0	3.0	4.0
4.0	1.0	4.0	6.0	3.0	3.0	2.0
2.0	3.0	2.0	2.0	4.0	3.0	4.0
2.0	4.0	3.0	4.0	3.0	3.0	1.0
3.0	3.0	3.0	1.0	3.0	1.0	4.0
2.40	3.00	3.00	3.20	3.80	2.60	3.00 = means
1.02	1.10	0.63	1.72	1.17	0.60	1.26 = SD's

Mean of means 3.00
Mean of standard deviations 1.10

Gp 10XA Style PSI MAY 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
3.0	2.0	2.0	3.0	4.0	3.0	4.0
6.0	2.0	2.0	1.0	6.0	3.0	4.0
3.0	2.0	3.0	2.0	5.0	3.0	5.0
5.0	3.0	3.0	2.0	5.0	3.0	3.0
5.0	2.0	3.0	1.0	6.0	2.0	3.0
6.0	1.0	5.0	1.0	6.0	4.0	4.0
6.0	3.0	2.0	3.0	5.0	3.0	6.0
3.0	2.0	5.0	1.0	6.0	6.0	4.0
3.0	1.0	2.0	1.0	6.0	6.0	1.0
2.0	2.0	1.0	1.0	6.0	6.0	6.0
4.0	1.0	6.0	1.0	6.0	4.0	1.0
4.0	4.0	2.0	1.0	6.0	2.0	3.0
3.0	3.0	3.0	1.0	6.0	4.0	3.0
3.0	3.0	1.0	1.0	6.0	2.0	3.0
2.0	3.0	5.0	2.0	4.0	3.0	6.0
2.0	3.0	3.0	2.0	3.0	3.0	5.0
3.0	3.0	1.0	1.0	6.0	6.0	4.0
4.0	2.0	3.0	3.0	5.0	2.0	6.0
6.0	6.0	4.0	5.0	3.0	4.0	3.0
4.0	1.0	2.0	4.0	5.0	3.0	3.0
5.0	3.5	2.0	1.0	6.0	3.0	3.0
6.0	4.0	3.0	1.0	6.0	2.0	1.0
6.0	2.0	3.5	2.0	4.0	3.0	1.0
3.0	2.0	3.5	1.0	3.0	4.0	3.0
4.04	2.52	2.92	1.75	5.17	3.50	3.54 = means
1.40	1.13	1.31	1.09	1.07	1.29	1.55 = SD's

Mean of means 3.348
Mean of standard deviations 1.264

Gp 1OXB Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
3.0	3.0	3.0	1 .0	6.0	4 .0	4.0
3.0	5.0	6.0	1.0	6.0	6.0	2.0
3.0	2.0	2.0	2.0	6.0	4.0	2.0
6.0	2.0	3.0	1.0	6.0	4.0	3.0
5.0	1.0	3.0	2.0	6.0	5.0	1.0
1.0	4.0	1.0	1.0	6.0	1.0	5.0
1.0	4.0	3.0	1.0	6.0	1.0	6.0
1.0	4.0	3.0	1.0	6.0	1.0	6.0
2.0	3.0	3.0	4.0	4.0	4.0	4.0
4.0	2.0	2.0	3.5	4 0	3.0	3.0
3.0	2.0	2.0	1.0	6.0	3.0	4.0
2.0	2.0	3.0	3.0	5.0	1.0	5.0
3.0	4.0	3.0	1.0	4.0	2.0	5.0
3.0	3.0	1.0	1.0	5.0	3.0	3.0
3.0	2.0	1.0	1.0	6.0	3.0	3.0
3.0	3.0	3.0	3.0	4.0	3.0	4.0
3.0	1.0	1.O	1.0	6.0	3.0	4.0
3.0	3.0	3.0	1.0	6.0	1.0	4.0
3.0	3.0	1.0	1.0	6.0	2.0	5.0
2.89	2.79	2.47	1.61	5.47	2.84	3.84 = means
1.21	1.06	1.19	0.98	0.82	1.42	1.31 = SD's

Mean of means 3.132
Mean of standard deviations 1.140

Gp 1OC Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
5.0	3.5	6.0	1.o	6.0	6.0	6.0
5.0	4.0	2.0	1.o	6.0	4.0	5.0
6.0	2.0	2.0	1.o	5.0	3.0	3.0
6.0	4.0	4 0	6.0	2.0	4.0	4.0
4.0	5.0	2.0	2.0	6.0	2.0	4.0
5.0	3 o	2.0	1.0	6.0	3.0	3.0
5.0	5.0	2.0	1.0	5.0	2.0	3.0
6.0	5.0	1.0	1.0	6.0	4.0	5.0
6.0	5.0	1.0	1.0	6.0	3.5	5.0
4.0	4.0	3.0	1.0	6.0	4.0	4.0
6.0	6.0	4.0	4.0	3.0	4.0	4.0
4.0	4.0	4.0	4.0	3.0	4.0	3.0
4.0	3.0	4.0	5.0	3.0	4.0	3.0
6.0	4.0	4.0	4.0	3.0	4.0	3.0
b.0	20	50	6.0	30	1.0	6.0
3.0	3.0	3.0	3.0	6.0	3.0	3.0
4.0	3.0	3.0	3.0	5.0	4.0	3.0
4.0	2.0	1.0	2.0	6.0	4.0	5.0
4.94	3.75	2.94	2.61	4.78	3.53	4.00 = means
0.97	1.13	1.39	1.77	1.44	1.06	1.05 = SD's

Mean of means 3.794
Mean of standard deviations 1.259

Gp 10YA Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
6.0	Z.0	1.0	3.0	6.0	3.0	4.0
3.0	1.0	1.0	1.0	6.0	4.0	2.0
Z.O	2.0	3.0	2.0	5.0	3.5	4.0
4.0	3.0	4.0	2.0	6.0	3.0	4.0
4.0	1.0	3.0	1.0	6.0	5.0	2.0
6.0	1.0	2.0	2.0	4.0	2.0	5.0
6.0	1.0	3.0	1.0	5.0	1.0	5.0
6.0	3.0	4.0	1.0	6.0	6.0	5.0
6.0	3.0	2.0	1.0	5.0	3.0	5.0
6.0	2.0	3.0	1.0	5.0	6.0	4.0
6.0	3.0	4.0	1.0	1.0	6.0	3.0
6.0	2.0	1.0	1.0	6.0	3.0	3.5
6.0	1.0	2.0	1.0	6.0	2.0	1.0
4.0	4.0	4.0	2.0	4.0	4.0	5.0
6.0	6.0	4.0	1.0	6.0	2.0	2.0
2.0	1.0	2.0	1.0	6.0	3.5	5.0
6.0	3.0	4.0	1.0	1.0	6.0	3.0
4.94	2.29	2.76	1.35	4.94	3.71	3.68 = means
1.43	1.32	1.11	0.59	1.59	1.55	1.27 = SD's

Mean of means 3.382
Mean of standard deviations 1.267

Gp 1OYB Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
3.0	3 0	4.0	1.0	6.0	3.0	6.0
5.0	3.0	2.0	2.0	5.0	3.5	3.0
1.0	3.0	3.0	2.0	6.0	6.0	1.0
5.0	3.0	1.0	1.0	5.0	3.0	5.0
6.0	2.0	2.0	3.0	3.5	5.0	3.0
2.0	1.0	1.0	1.0	6.0	1.0	4.0
6.0	3.0	2.0	1.0	6.0	3.0	3.0
6.0	4.0	3.5	1.0	6.0	4.0	4.0
3.0	3.0	2.0	1.0	6.0	4.0	2.0
6.0	5.0	2.0	1.0	6.0	4.0	1.0
6.0	5.0	2.0	1.0	6.0	4.0	2.0
6.0	5.0	2.0	1.0	6.0	4.0	2.0
3.0	4.0	4.0	1.0	4.0	3.0	3.0
2.0	3.0	3.5	3.5	2.0	2.0	4.0
2.0	4.0	4.0	2.0	4.0	6.0	3.0
6.0	6.0	5.0	6.0	5.0	4.0	3.0
2.0	1.0	4.0	3.0	3.0	5.0	5.0
4.12	3.41	2.76	1.85	5.03	3.79	3.18 = means
1.64	1.33	1.15	1.33	1.24	1.25	1.34 = SD's

Mean of means 3.450
Mean of strandard deviations 1.355

Gp 10YC Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33	
5.0	3.5	4.0	2.0	2.0	4.0	3.0	
5.0	1.0	2.0	1.0	6.0	4.0	6.0	
4.0	5.0	4.0	5.0	6.0	6.0	6.0	
6.0	3.0	3.0	1.0	6.0	5.0	6.0	
6.0	4.0	3.0	2.0	6.0	5.0	6.0	
4.0	2.0	3.0	1.0	6.0	3.0	5.0	
6.0	3.0	4.0	1.0	5.0	5.0	5.0	
2.0	2.0	4.0	1.0	6.0	2.0	6.0	
2.0	4.0	3.0	2.0	6.0	5.0	6.0	
5.0	2.0	4.0	2.0	2.0	4.0	3.0	
1.0	3.0	2.0	5.0	6.0	4.0	4.0	
4.0	3.0	3.0	5.0	6.0	4.0	6.0	
3.5	3.5	3.5	6.0	3.5	3.5	3.5	
4.12	3.00	3.27	2.62	5.12	4.19	5.04 = means	
1.57	1.02	0.70	1.82	1.50	0.99	1.18 = SD's	

Mean of means 3.907
Mean of standard deviations 1.254

Gp 10YD Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33	
3 0	2.0	3.0	4.0	6.0	4.0	2.0	
3.0	3.0	2.0	3.0	6.0	3.0	4.0	
6.0	1.0	1.0	1.0	6.0	4.0	6.0	
6.0	1.0	1.0	1.0	6.0	6.0	6.0	
6.0	4.0	3.0	1.0	5.0	4.0	3.5	
6.0	5.0	2.0	5.0	2.0	3.0	3.0	
6.0	6.0	3.0	2.0	4.0	3.0	4.0	
6.0	4.0	4.0	2.0	3.5	2.0	4.0	
1.0	1.0	1.0	1.0	6.0	6.0	6.0	
4.78	3.00	2.22	2.22	4.94	3.89	4.28 = means	
1.81	1.76	1.03	1.40	1.38	1.29	1.36 = SD's	

Mean of means 3.619
Mean of standard deviations 1.433

Gp 10YE Style PS1 May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33	
3.0	2.0	3.0	1.0	6.0	2.0	4.0	
4.0	4.0	2.0	1.0	6.0	3.0	5.0	
6.0	3.5	3.0	4.0	2.0	5.0	3.0	
4.0	5.0	3.5	1.0	6.0	6.0	1 .0	
1.0	3.5	6.0	6.0	6.0	1.0	1 .0	
6.0	6.0	1.0	4.0	4.0	3.0	5.0	
4.00	4.00	3.08	2.83	5.00	3.33	3.17 = mean	
1.73	1.26	1.54	1.95	1.53	1.70	1.67 = SD	

Mean of means 3.631
Mean of standard deviations 1.626

Gp 10K red Style PSl May 1994

Q3	Q8	Q13	Q18	Q23	Q28	Q33
3.5	z.o	4.0	1.0	5.0	2.0	1.0
5.0	4.0	5.0	1.0	6.0	1.0	5.0
3.0	5.0	3.0	2.0	5.0	4.0	5.0
3.0	3.0	2.0	1.0	4.0	4.0	3.0
5.0	1.0	3.0	2.0	5.0	5.0	3.0
5 0	1.0	1.0	2.0	5.0	5.0	2.0 - test case
3.0	3.0	1.0	2.0	5.0	4.0	4.0
2.0	3.0	1.0	1.0	5.0	6.0	6.0
3.0	5.0	2.0	1.0	6.0	2.0	2.0
5.0	4.0	2.0	2.0	4.0	2.0	3.5
5.0	3.0	3.0	2.0	4.0	4.0	2.0
3.0	3.0	2.0	2.0	6.0	4.0	3.0
4.0	3.0	1.0	1.0	6.0	4.0	3.0
6.0	6.0	1.0	1.0	6.0	1.0	6.0
4.0	2.0	2.0	2.0	6.0	3.5	4.0
3.0	2.o	2.0	1.0	6.0	4.0	3.0
3.0	2.0	2.0	1.0	5.0	4.0	3.0
3.0	3.0	1.0	1.0	4.0	1.0	5.0
4.0	3.0	1.0	1.0	4.0	1.0	5.0
5.0	2.0	2.0	1.0	6.0	3.0	1.0
6.0	3.0	1.0	1.0	5.0	1.0	4.0
6.0	3.0	3.0	1.0	6.0	1.0	6.0
4.07	3.00	2.05	1.36	5.22	3.02	3.61 =means
1.17	1 .21	1.07	0.48	0.81	1.54	1.49 = SD's

Mean of means 3.198
Mean of standard deviations 1.109

Gp lOK yellow Style PS1 May 1994

Q8	Q8	Q13	Q18	Q23	Q28	Q33
4.0	4.0	6.0	4.0	6.0	3.0	4.0
6.0	1.0	4.0	1.0	6.0	6.0	4.0
6.0	4.0	4.0	1.o	5.0	3.0	5.0
6.0	3.0	4.0	1.0	6.0	2.0	3.0
1.0	1.0	3.0	1.0	6.0	2.0	1.0
2.0	3.0	4.0	6.0	6.0	3.0	1.0
3.0	2.0	2.0	3.0	5.0	5.0	5.0
3.0	3.0	2.0	1.0	1.0	3.0	4.0
4.0	3.0	1.0	1.0	6.0	5.0	5.0
6.0	1.0	3.0	1.0	6.0	1.0	2.0
1.0	2.0	1.0	2.0	5.0	2.0	3.0
5.0	2.0	4.0	3.0	5.0	5.0	4.0
4.0	1.0	3.0	1.0	6.0	5.0	2.0
6.0	2.0	3.0	1.0	6.0	1.0	2.0
3.0	2.0	4.0	1.0	6.0	5.0	2.0
5.0	3.0	2.0	1.o	6.0	5.0	3.0
4.0	2.0	5.0	3.0	6.0	5.0	5.0
4.06	2.35	3.29	1.88	5.47	3.59	3.18 = Means
1.66	1 .03	1.32	1.41	1.91	1 .57	1.34 = SD's

Mean of means 3.403
Mean of standard deviations 1.360

Whole sample: style - problem solving (PS1) response means

Date	Group	Q3	Q8	Q13	Q18	Q23	Q28	Q33
27 05 94	10 XA	4.04	2.52	2.92	1.75	5.17	3.50	3.54
10 05 94	10 XB	2.89	2.79	2.47	1 .61	5.47	2.84	3.84
23 05 94	10 XC	4.94	3.75	2.94	2.61	4.78	3.53	4.00
05 03 94	10 YA	4.04	2.29	2.76	1.35	4.94	3.71	3.68
03 05 94	10 YB	4.12	3.41	2.76	1 .85	5.03	3.79	3.18
03 05 95	10 YC	4.12	3.00	3.27	2.62	5.12	4.19	5.10
03 05 94	10 YD	4.78	3.00	2.22	2.22	4.94	3.89	4.28
03 05 94	10 YE	4.00	4.00	3.08	2.83	5.00	3.33	3.17
14 12 92	10 K red	4.07	3.00	2.05	1.36	5.27	3.02	3.61
14 12 92	10K yell	4.06	2.35	3.29	1.88	5.47	3.59	3.18
27 03 95	6th form	2.40	3.00	3.00	3.20	3.80	2.60	3.00
means		4.033	3.010	2.796	2.116	4.999	3.454	3.689
Whole sample mean			3.4425					

Section 6 - Pupil questionnaire response analyses:
Problem solving (PS2) style for year 10 and year 12 pupils

Gp 10A Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
4.0	4.0	4.0	3.0	3.0	2.0	3.0
4.0	2.0	3.0	5.0	3.0	3.0	2.0
5.0	2 0	4.0	2.0	3.0	Z.0	2.0
2.0	3.0	4.0	3.0	3.0	1.0	3.0
3.0	2.0	5.0	3.0	3.0	2.0	4.0
1.0	1.0	6.0	4.0	1.0	1.0	1.0
3.0	2.0	4.0	4.0	4.0	2.0	1.0
2.0	3.0	6.0	6.0	6.0	3.0	5.0
4.0	Z.0	6.0	5.0	5.0	1.0	4.0
2.O	2.0	5.0	4.0	5.0	3.0	4.0
2.0	2.0	6.0	6.0	5.0	3.0	6.0
4.0	5.0	6.0	6.0	6.0	3.0	4.0
2.0	1.0	6.0	1.0	6.0	1.0	1.0
3.5	4.0	6.0	2.0	5.0	4 0	3.0
2.O	2.O	4.0	3.0	5.0	3.0	3.0
3.0	3 0	3.0	4.0	2.0	3.0	2.0
3.0	2.0	6.0	1.0	6.0	3.0	3.0
2.0	2.O	2.0	4 0	2.0	3.0	6.0
5.0	4.0	3.0	3.0	3.5	3.5	3.5
3.0	1.0	2.0	2.0	4.0	2.0	2.0
3.0	1.0	3.5	3.0	2.0	3.0	1.0
5.0	1.0	6.0	1.0	3.0	1.0	2.0
4.0	2.0	5.0	4.0	4.0	2.0	6.0
3.0	2.0	3.0	4.0	3.0	2.0	2.0
3.10	2.29	4.52	3.46	3.85	2.35	3.06 = means
1.08	1.06	1.37	1.47	1.43	0.87	1.54 = SD's

Mean of means = 3.325
Mean of standard deviations =1.260

Gp 10B Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
5.0	2.0	6.0	s o	3.0	3.0	3.0
3.5	5.0	6.0	4.0	6.0	5.0	6.0
4.0	3.0	3.0	2.0	2.0	2.0	2.0
5.0	1.0	4.0	4.0	3.0	3.0	4.0
5.0	1.0	4.0	4.0	5.0	4.0	5.0
3.0	4.0	5.0	2.0	3.0	3.0	5.0
3.0	4.0	5.0	2.0	3.0	3.0	5.0
3.0	4.0	5.0	2.0	3.0	3.0	5.0
3.0	3.0	3.0	4.0	2.0	5.0	3.0
4.0	3.5	4.0	3.0	3.0	2.0	3.0
3.0	2.0	2.0	3.0	2.0	3.0	4.0
1.0	3.0	3.0	2.0	3.0	3.5	3.0
4.0	2.0	6.0	3.0	3.0	3.0	2.0
3.0	2.0	4.0	1.0	5.0	1.0	3.0
2.0	2.0	4.0	1.0	5.0	1.0	3.0
2.0	3.0	4.0	3.0	3.0	3.0	4.0
2.0	1.0	3 o	1 o	2.0	1.0	6.0
3.0	1.0	3.0	3.0	2.0	2.0	5.0
2.0	4.0	3.0	2.0	3.0	2.0	2.0
3.18	2.66	4.05	2.68	3.21	2.76	3.84 = means
1.09	1.19	1.15	1.13	1.15	1.13	1.27 = SD's

Mean of means = 3.199
Mean of standard deviations =1.157

Gp 10C Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
6.0	4.0	6.0	6.0	6.0	6.0	3.0
6.0	4.0	6.0	3.0	5.0	5.0	3.0
5.0	1.0	4.0	5.0	3.0	3.0	3.0
6.0	4.0	4.0	5.0	4.0	4.0	3.0
5.0	2.0	2.0	4.0	5.0	2.0	4.0
1.0	2.0	3.0	1.0	2.0	2.0	5.0
3.0	4.0	5.0	3.5	3.5	4.0	3.0
5.0	2.0	6.0	5.0	4.0	3.0	6.0
5.0	1.0	6.0	5.0	1.0	3.0	6.0
3 o	1.0	30	4.0	2.0	4.0	5.0
6.0	2.0	4.0	6.0	3.0	4.0	6.0
4.0	5.0	3.0	3.0	5.0	4.0	4.0
2.0	4.0	3.0	1.0	2.0	2.0	2.0
3.0	2.0	3.0	2.0	1.0	3.0	3.0
3.0	2.0	5.0	2.0	3.0	2.0	4.0
3.0	2.0	5.0	2.0	2.0	3.0	2.0
4.13	2.63	4.44	3.59	3.22	3.38	3.88 = means
1.54	1.27	1.17	1.61	1.47	1.11	1.32 = SD's

Mean of means = 3.607
Mean of standard deviations =1.355

Gp lOYA Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	1 o	2.0	2.0	2.0	3.0	6.0
1.0	1.0	5.0	1.0	2.0	2.0	4.0
3.0	3.0	3.0	5.0	4.0	3.0	3.0
4.0	3.0	3.0	1.0	1.0	2.0	2.0
4.0	2.0	5.0	1.0	4.0	3.0	2.0
2.0	1.0	2.0	1.0	2.0	2.0	2.0
1.0	1.0	2.0	2.0	2.0	2.0	2.0
5.0	3.0	5.0	2.0	5.0	2.0	2.0
5.0	2.0	6.0	3.0	5.0	5.0	5.0
4.0	4.0	6.0	3.0	6.0	2.0	4.0
4.0	3.0	6.0	6.0	4.0	1.0	6.0
6.0	2.0	4.0	3.0	5.0	2.0	2.0
6.0	3.0	5.0	3.5	1.0	1.0	1.0
2.0	3.0	3.0	2.0	5.0	3.0	5.0
3.0	2.0	5.0	2.0	3.0	3.0	5.0
4.0	2.0	4.0	4.0	3.0	3.0	2.0
1.0	3.0	6.0	6.0	4.0	1.0	6.0
3.35	2.29	4.24	2.79	3.41	2.35	3.47 = means
1.61	0.89	1 44	1.60	1.50	0.97	1.68 = SD's

Mean of means = 3.130
Mean of standard deviations =1.383

Gp 10YB Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35	
2.0	3.0	6.0	2.0	2.0	5.0	6.0	
3.0	2.0	1.0	2.0	3.0	2.0	2.0	
2.0	2.0	2.0	2.0	4.0	3.0	3.0	
3.5	3.0	2.0	5.0	4.0	3.0	2.0	
2.0	2.0	4.0	1.0	3.0	3.0	2.0	
1.0	1.0	3.0	1.0	3.0	2.0	1.0	
2.0	1.0	4.0	2.0	4.0	2.0	1.0	
4.0	4.0	6.0	4.0	4.0	4.0	6.0	
4.0	3.0	4.0	3.0	4.0	4.0	4.0	
5.0	2.0	6.0	2.0	6.0	1.0	4.0	
5.0	2.0	2.0	4.0	4.0	2.0	2.0	
6.0	2.0	6.0	4.0	4.0	3.0	2.0	
4.0	4.0	4.0	2.0	3.0	3.0	3.0	
3.0	4.0	3.0	2.0	2.0	3.0	2.0	
3.0	3.5	1.0	2.0	1.0	3.0	5.0	
6.0	6.0	5.0	4.0	3.0	2.0	4.0	
4.0	5.0	1.0	3.0	2.0	2.0	5.0	
3.50	2.91	3.53	2.65	3.47	2.76	3.18	= means
1.41	1.33	1.79	1.13	1.14	0.94	1.58	= SD's

Mean of means = 3.143
Mean of standard deviations = 1.333

Gp 10YC Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35	
3.0	3.5	4.0	4.0	5.0	3.0	3.0	
4.0	2.0	3.0	4.0	4.0	3.0	5.0	
3.0	4.0	6.0	5.0	6.0	6.0	6.0	
4.0	3.0	6.0	5.0	3.0	1.0	2.0	
4.0	3.0	6.0	5.0	3.0	1.0	2.0	
2.0	3.0	4.0	4.0	4.0	3 0	6.0	
6.0	3.0	4.0	2.0	2.0	5.0	1.0	
2.0	3.0	4.0	3.0	5.0	3.0	4.0	
3.5	4.0	6.0	5.0	3.0	1.0	2.0	
3.0	3.0	4.0	4.0	5.0	3.0	3.0	
4.0	4.0	4.0	3.0	3.0	4.0	3.0	
2.0	4.0	4.0	4.0	3.0	4.0	6.0	
3.5	3.5	3.5	3.5	3.5	1.0	3.5	
3.30	3.31	4.50	3.96	3.81	2.92	3.58	= means
1 .06	0.57	1.04	0.89	1.10	1 .54	1.64	= SD's

Mean of means = 3.637
Mean of standard deviations =1.120

Gp 10YD Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	2.0	4.0	2.0	4.0	2.0	4.0
3.0	2.0	2.0	2.0	2.0	3.0	3.0
1.0	1.0	2.0	1.0	4.0	2.0	3.0
5.0	1.0	2 0	2.0	1.0	3.0	2.0
5.0	5.0	5.0	4.0	3.0	4.0	3.5
6.0	4.0	4.0	3.0	1.0	3.5	4.0
5.0	5.0	6.0	5.0	2.0	5.0	3.0
5.0	6.0	6.0	2.0	3.0	4.0	3.0
1.0	6.0	6.0	1.0	1.0	1.0	1.0
3.67	3.56	4.11	2.44	2.33	3.06	2.94 = means
1.83	1.95	1.66	1.26	1.15	1.17	0.90 = SD's

Mean of means = 3.159
Mean of standard deviations =1.416

Gp 10YE Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	1.O	2.0	1 o	2.0	3.0	2.0
3.5	3.0	3.0	1.O	2.0	3.0	3.0
2 o	1.0	5.0	3.0	1.0	3 0	5 0
5.0	5.0	3.5	3.0	5.0	4.0	4.0
6.0	5.0	3.5	6.0	3.s	1.0	1.0
6.0	1.0	1.0	5.0	4.0	2.0	3.5
4.08	2.83	3.00	3.17	2.92	2.67	3.08 = means
1.69	2.03	1.26	1.86	1.37	0.94	1.30 = SD's

Mean of means = 3.607
Mean of standard deviations =1.355

Gp 10K yellow Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	4 0	3.0	1.0	3.0	3.0	1.0
4.0	2.0	6.0	5.0	6.0	3.0	4.0
4.0	1.0	4.0	1.0	3.0	2.0	2.0
6.0	3.0	5.0	3.0	4.0	2.0	3.5
2.0	2.0	5.0	1.0	4.0	1.0	1.0
4.0	4.0	5.0	1.0	1.0	6.0	1.0
5.0	2.0	2.0	2.0	4.0	3.0	4.0
5.0	2.0	5.0	3.0	2.0	4.0	3.0
2.0	1.0	6.0	5.0	6.0	2.0	3.0
3.0	1.0	5.0	1.0	4.0	2.0	1.0
3.5	3.0	2.0	1.0	3.0	3.0	3.0
5.0	1.0	5.0	5.0	4.0	1.0	5.0
3.0	2.0	2.0	2.0	5.0	4.0	3.0
4.0	1.0	5.0	1.0	4.0	2.0	1.0
2.0	3.0	2.0	1.0	6.0	1.0	1.0
2.0	2.0	4.0	1.0	3.0	1.0	1.0
2.0	2.0	5.0	2.0	5.0	1.0	1.0
3.44	2.12	4.18	2.12	3.94	2.41	2.26 = means
1.20	0.96	1.30	1.49	1.35	1.33	1.33 = SD's

Mean of means = 2.924
Mean of standard deviations =1.304

Gp 10 K red Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
2.0	2.0	3.0	2.0	4.0	1.0	1.0
5.0	3.0	4.0	4.0	2.0	4.0	5.0
2.0	1.0	3.0	2.0	3.0	2.0	3.0 - test case
3.0	3.0	3.0	2.0	3.0	2.0	2.0
3.0	1.0	5.0	4.0	6.0	3.0	3.0
3.0	1.0	3.0	2.0	2.0	2.0	3.0
3.0	2.0	3.0	3.0	3.0	3.5	3.0
3.0	3.0	6.0	4.0	1.0	3.0	3.0
4.0	3.0	6.0	3.0	3.0	2.0	2.0
4.0	3.0	4.0	2.0	2.0	2.0	2.0
3.0	3.0	4.0	4.0	2.0	2.0	3.0
3.0	1.0	4.0	5.0	2.0	3.0	3.0
1.0	2.0	4.0	1.0	1.0	1.0	3.0
3.0	1.0	6.0	1.0	1.0	1.0	1.0
2.0	3.0	5.0	1.0	5.0	4.0	4.0
2.0	1.0	4.0	2.0	3.0	2.0	3.0
2.0	1.0	4.0	2.0	4.0	2.0	3.0
3.0	3.0	2.0	2.0	3.0	2.0	1.0
3.0	2.0	2.0	2.0	2.0	1.0	1.0
3.0	1.0	6.0	1.0	1.0	1.0	1.0
4.0	1.0	5.0	1.0	1.0	3.5	1.0
3.0	1.0	6.0	1.0	2.0	1.0	1.0
3.00	2.05	4.18	2.32	2.55	2.27	2.36 = means
0.74	1.11	1.27	1.18	1.30	0.95	1.11 = SD's

Mean of means = 2.675
Mean of standard deviations =1.094

Gp 6th form Style PS2

Q5	Q10	Q15	Q20	Q25	Q30	Q35
3.0	2.0	3.0	2.0	3.0	2.0	2.0
3.0	5.0	3.0	4.0	4.0	4.0	2.0
3.0	1.0	4.0	2.0	3.0	1.0	3.0
4.0	1.0	2.0	1.0	5.0	1.0	1.0
5.0	2.0	s.o	3.0	3.0	3.0	5.0
3.60	2.20	3.40	2.40	3.60	2.20	2.60 = means
0.80	1.47	1.02	1.02	0.80	1 17	1.36 = SD's

Mean of means = 2.857
Mean of standard deviations =1.090

Whole sample: style - problem solving (PS2) response means

Date	Group	Q5	Q10	Q15	Q20	Q25	C30	C35
27 05 94	10 A	3.10	2.29	4.52	3.46	3.85	2.35	3.06
10 05 94	10 B	3.18	2.66	4.05	2.68	3.21	2.76	3.84
23 05 94	10 C	4.13	2.63	4.44	3.59	3.22	338	3.88
05 03 94	10 YA	3.35	2.29	4.24	2.79	3.41	2.35	3.47
03 05 94	10 YB	3.50	2.91	3.53	2.65	3.47	2.76	3.18
03 05 94	10 YC	3.38	3.31	4.50	3.96	3.81	2.92	3.56
03 05 94	10 YD	3.76	3.56	4.11	2.44	2.33	3.06	2.94
03 05 94	10YE	4.08	2.83	3.00	3.17	2.92	2.67	3.08
14 12 92	10 K red	3.00	2.05	4.18	2.32	2.55	2.27	2.36
14 12 92	10 K yellow	3.44	2.12	4.18	2.12	3.94	2.41	2.26
27 03 95	6th form	3.60	2.20	3.40	2.40	3.60	2.20	2.60
	means	3.502	2.623	3.759	2.870	3.065	2.550	3.029

Whole sample mean 3.0488