EDUCATIONAL PROBLEMS IN WRITING CHEMICAL FORMULAE AND EQUATIONS

BY

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ABSTRACT

The difficulties existing for many pupils in the areas of formulae and equations and the belief that many of these problems were due to maturity barriers, led to the inauguration of this study in 1970.

A preliminary survey was made of the situation extant in 1970 concerning these topics. This revealed a very confused picture with wide variation of teacher approach. The most obvious problem was one of over-complexity in formulae and equations. Teachers were teaching with little or no regard for the developmental ideas of Piaget et al.

This problem was investigated at school level by a test based on a Gagné net for the writing of formulae and by a questionnaire. This test was examined in depth and confirmed the indications gathered in the preliminary survey. Pupils did not appear to reason logically when writing formulae but rather committed certain common formulae to memory, and failure at one step in the thought process did not appear to affect performance in the next. The very high number of pupils unable to handle proportion (71%) calculations from equations (97%) was disturbing, (the problem may be purely mathematical,) and many pupils showed a lack of understanding of even the most basic principles e.g. nomenclature, formation of ions. Pupils seemed able to cope with individual steps in e.g. formula writing, but could not handle all the material "en bloc" when it was presented in a very short time (2 - 3 months). This meant that overall performance was very poor (28% correct). A re-run of part of this test confirmed these results.

The questionnaire revealed that pupils tended to underestimate the difficulty of many topics and that teachers were more consistent than them in their estimates of difficulty.

The teaching order of the 'O' grade course in Chemistry was then examined in the light of the degree of complexity in formulae and equations needed for each section. A revised teaching order, which was basically 'organic first' was drawn up using the principle of gradual revelation of these topics.

To evaluate this revised order a maturity study was set up, having both experimental and control groups. The progress of the groups was monitored by a series of short tests, the results of which, and the 1973 'O' grade examination in Chemistry were analysed. No significant differences were found, but following the revised order did not disadvantage pupils over those following the standard orders. In fact there was some evidence to show that the revised order had achieved for these pupils, a higher level of understanding on the more difficult topics, especially calculations from equations and the mole. They also were more consistent in their level of performance on writing formulae.

A detailed analysis of the last test (an overall revision of the work) was carried out and showed the same problems as were evident in the Gagné study e.g. interpretation of nomenclature such as the difference between - IDE and - ITE compounds. Some topics appeared to be still beyond the majority of pupils e.g. (i) extrapolation from Na_2CO_3 to Na_2SiO_3 (12%) (ii) writing balanced equations (20%) (iii) calculations from equations (20%).

However pupils did seem to grasp the mathematical rules for formulae writing reasonably competently.

A similar questionnaire to that used in the first investigation revealed that in general the revised group found the course easier than the control groups and that pupils now overestimated the difficulty of those topics previously underestimated.

A final survey in 1974 showed a situation on the one hand eased by the removal of a recall barrier in formula writing and on the other worsened by the choice of the correct level of complexity of formulae to be used in any questions being left to the pupil.

Recommendations were made for lessening the amount of conceptually difficult material (Piaget Stage 3) in the '0' grade syllabus and its replacement by work involving lower order skills, including purely practical ones.

INTRODUCTION

While teaching a group of girls at the lower end of the ability scale within a selective school (V.R.Q. Range 105-112) in 1967, it had become obvious to the author that great problems lay in the area of formulae, equations, the mole and 'ionic' work in general. The level of complexity of thought being demanded of these girls appeared to be in excess of their conceptual development. Consequently the course teaching order was drastically changed at Christmas of their third year (1967) and subsequently they proceeded on an "organic first" approach. Two classes were presented at '0' grade in May 1969 with mixed results.

A. H. Johnstone set up his maturity study in August 1969(1) to examine on a systematic basis the maturity barriers existing within the '0' grade syllabus. This, however, did not deal at all with formulae, equations, the mole and calculations, concerning itself with the 'ionic' work such as redox equations, conductivity, pH etc.

The culmination of much discussion during 1969/70 was that a study should be set up to examine the position of formulae and equations within the context of the S.C.E.E.B. '0' grade Syllabus(2). This present study was inaugurated in June 1970 and set out to:-

(1) consider the present situation on formulae and equations from the teachers standpoint,

(2) examine the problem at pupil level,

(3) conduct a maturity study by devising a revised teaching order to place difficult conceptual material, including formulae and equations, later in the teaching order, and subjecting this to evaluation with as wide a group of pupils as possible,

(4) make recommendations for any future revision of the S.C.E.E.B. '0' grade syllabus(2).

CHAPTER I.

GENERAL INTRODUCTION AND PRELIMINARY REVIEW OF THE SITUATION IN 1970

Situation Extant in 1970

The alternative 'O' grade syllabus in Chemistry first published as Circular 512(3) and revised in 1969(2), had been accepted so readily by teachers that within eight years the traditional syllabus had ceased to be examined. This brave new world of Chemistry teaching, which admittedly had arisen from the teaching situation(4) was not without its problems.

Objectives for this 'O' grade course were drawn up (retrospectively) and they include, at the cognitive level (as described by Bloom et al(5)).

Pupils should acquire in knowledge and understanding.

1. Knowledge and understanding of various symbols used by chemists with particular reference to their application in formulae and equations.
2. Understanding of the quantitative implications of many chemical symbols and formulae.
3. Ability to carry out relevant calculations based on formulae and equations.
4. Knowledge and understanding of systematic nomenclature as applied to chemical species.
5. Knowledge and understanding of some fundamental concepts in chemistry.
6. Knowledge and understanding of the chemistry of certain elements and their simple compounds.
7. Knowledge of some industrial processes in chemistry and an understanding of their significance in everyday life.
8. Knowledge and understanding of various chemical processes and their effects in everyday life.
9. Understanding of the chemist's ability to produce new compounds of desired structure and properties.
10. Ability to find, use and apply various types of information from a range of sources.

11. Understanding that chemical information can be classified in various ways and an ability to make use of some of these.

12. Ability to follow and criticise arguments about chemical ideas.

13. Ability to consider experimental evidence in terms of hypotheses and "models" (a) theoretical and (b) physical - both in two and three dimensions.

14. Ability to apply acquired knowledge and understanding to unfamiliar problems.

15. Ability to design experiments to check predictions and hypotheses deduced from available information.

16. Knowledge and understanding of the importance of observation in an experimental procedure.

17. Ability to assess the number and relative importance of variables in a situation.

18. Understanding of the use of controls in an experimental procedure.

19. Understanding of the limitations on accuracy involved in physical measurements.

20. Knowledge of laboratory equipment and skills sufficient to enable experimental procedures to be carried out adequately.

21. Knowledge and understanding of the reasons for carrying out appropriate safety regulations in the laboratory.

22. Ability to record and present information in various ways including graphical and diagrammatic representation as well as written statement.

23. Ability to apply scientific methods to other fields of experience.

It would appear that nearly half of these objectives - 1, 2, 3, 4, 9, 12, 13, 14, 15, 17 - require conceptual thinking at least of the stage 3(a) level as described by Piaget(6).

It will be shown later that this level of development is not reached by the majority of our population until 15+.

That the pupils were failing to achieve objectives 1 and 2, was evident from the annual reports of the S.C.E.E.B.(7) for 1967, 68, 69, which all draw attention to the inability of many candidates to write formulae and equations correctly.

With the switch of emphasis from "rote-learning", which so often was the approach under the old traditional syllabus, to the more enlightened way based on progressive understanding of the principles involved, memorandum No. 7 (8) had been issued by the S.E.D. Its purpose was to "examine the significance of symbols, formulae and equations in the teaching of modern elementary chemistry", and it has had considerable effect in influencing the development of these topics in Scottish schools. It is relevant at this stage to examine this document in some detail.

(1) Symbols

The recommendations were that two interpretations be placed on a symbol.

(a) "it is a shorthand way of writing the name of an element and simply means some of the element and pupils might be allowed to use symbols in this way in description of reactions."

(b) "in a balanced equation it may mean 1 mole of the element. Similarly in the equation

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

2HCl stands for 2 moles of hydrogen chloride."

Later work will show that pupils cannot interpret symbols correctly do not make the distinction between "some" and "1 mole", and that they do not appreciate the need for, or always recognise, a balanced equation. This is summed up in a previous paragraph in the memorandum (P.3.).

"The logical conclusion is that it should be permissable for pupils to use symbols instead of names in description of reactions,

PROVIDING THEY KNOW WHAT THE SYMBOLS MEAN."

(2) State Symbols

"Unless it is immediately obvious it is useful to add subscripts to the symbols to indicate the state of the substance concerned."

Later work will show that in fact state symbols appear to serve only to confuse the issue.

(3) Significance of Formulae

(i) "The formula of an ionic substance may be written indicating the charges on the ions.

$Zn^{2+}\ SO_{4\ (s)}^{2-}$ is solid zinc sulphate, anhydrous, or 1 mole of solid zinc sulphate, anhydrous. The presence of the charge indicates the ionic nature of the substance."

(ii) "The absence of any charge in a written formula indicates covalency; $H_2SO_{4(l)}$ represents covalent sulphuric acid."

(iii) "in a medium in which ionic substances can dissociate, $Zn^{2+}\ SO_4^{2-}$ is not a possible species. In water this can only be represented as $Zn^{2+}_{(aq)} + SO^{2-}_{4(aq)}$ and would mean Zinc ions and sulphate ions or 1 mole of Zinc ions and 1 mole of sulphate ions."

(iv) "Although this is undoubtedly the most accurate way of writing formulae, it must be left to the discretion of the teacher when to introduce these conventions."

Even though the memorandum did raise the possibility of doubt as to the type of bonding in compounds such as aluminium chloride, many teachers stuck rigidly to (i) and (ii), some going so far as to mark a 'covalent' formula for an 'ionic' compound as wrong e.g. $ZnSO_4$ would not be acceptable. It was suggested that $ZnSO_4$ might well be regarded as representing Zinc sulphate if it was clear that it did not set out to show how the substance was made up. Bearing in mind the recommendations as regards symbols, there can be little justification for even contemplating using formulae to convey complex structural information for inorganic/ionic materials e.g.

$$\left[Cu(H_2O)^{2+}\right]\left[SO_4(4H_2O)^{2-}\right] \quad (8)$$

especially when it should be

$$\left[Cu(H_2O)_4\right]^{2+}\left[SO_4(H_2O)\right]^{2-}$$

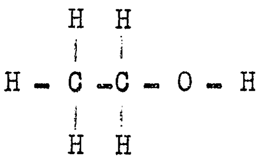
Formulae which are derived by analysis, were first used to convey stoichiometry rather than structure, and this is surely the level of approach needed for the majority of school use. The only need for using even Zn^{2+} SO_4^{2-} would be when reactions involving individual ions are being considered in detail.

In the words of the text - "A fair amount of chemical knowledge must therefore, be assumed before the universal use of ionic formulae could be expected. In addition, it may serve no useful purpose to be so precise."

The problem area of 'organic' found by A. H. Johnstone in his work(1) might well be due to the paragraph

"for certain purposes it is satisfactory to write the formula of ethyl alcohol as C_2H_6O, more often it is useful to write it as C_2H_5OH and OCCASIONALLY it MAY (capitals mine) be desirable to write it as CH_3CH_2OH."

In organic chemistry where so much of understanding can depend on understanding of the correct structure, and where formulae can be deduced in a semi-concrete fashion, using symbols and bonds, it is surely ESSENTIAL ALWAYS to write ethanol as either



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & O - H \\ & & | & & | & & \\ & & H & & H & & \end{array} \qquad \text{or} \qquad CH_3CH_2OH$$

in the formative years.

Later work will show that although technically more precise, pupils have greater difficulty in handling information when it is presented in the form suggested in (iii).

The memorandum did suggest that "these ideas might be introduced as the pupil becomes ready for them and as the need arises. Unfortunately when teachers read (iv) this advice was often ignored and pupils were introduced to the most complex formulae at the beginning and used them for all situations whether necessary or not.

In 1969, the consultative committee on the Curriculum published Curriculum Papers No.7 (9) entitled 'Science for General Education'. This listed the kinds of thinking that a pupil could be expected to use in his science education, in hierarchical order of complexity

In comprehending knowledge	In application of knowledge	In analysis, synthesis and evaluation of knowledge
observing	rearranging	justifying
comparing	relating	assuming
classifying	explaining	inferring
summarising	predicting	imagining
interpreting	estimating	inventing
discriminating		discovering
illustrating		generalising
extrapolating		hypothesising
		testing and re-assessing of hypotheses
		judging

Many of these involve quite high levels of conceptual thinking and would appear at first sight to be a goal to aim at for the completion of a chemistry course at school level. While seeming to accept the developmental approach to child learning -

"It had already been recognised that the original examination syllabuses in modern physics and chemistry contained not only too much content but also that some of it was conceptually too difficult for the stage of development of the children being taught".

- the papers made several statements which appear not to take full cognisance of this.

For example

(i) "there is evidence to suggest that it may be possible to obtain, from a much wider band of pupils than has formerly been assumed, thinking of a quite highly involved kind, and it may be that in the past less credit than he was due has been given to the so-called less able pupil, what he may lack in memory span, he may not also lack in ability to think."

(ii) "Such results are much better than we had any reason to hope for, but justify our desire to include objectives of a fairly complex nature (- conceptual material which was rather abstract and quite complex; it demanded frequent application of knowledge to new situations, sometimes using several stages of thought to reach an answer -) for the full spectrum of intake at this early age."

(iii) "It could well be that some at least of any future revisions will be towards less demand upon memory and greater demands still on the ability to reason."

It is not surprising then that many teachers opted for the "Maximum" from the outset in the hope that the 'few' would come to an understanding later (and anyway the bright ones need the practice). As will be shown later, this 'few' turned out to be the 'majority'.

Developmental Theory

The work of Piaget(6) which has set out in some detail the conceptual development of the child through the stages of (i) sensorimotor (ii) concrete (iii) formal, operations, has been examined in some detail by Lovell(10) and Shayer (11) with respect to its relevance for science teaching. Lovell traces the development of measurement - essential to any science and first order relations e.g. the basic concepts of class, series, number, length, area, time, etc., during the age range 5 - 12(stage 2 in Piaget terms).

He stresses however, that while such relations are basic to science they are quite inadequate for the concepts required by science.

The new skills necessary e.g.

(i) deduction from information given

(ii) setting up a hypothesis, deducing what would happen if it held true and noting if the facts are consistent with the hypothesis

or in other words 'hypodeductive thought',

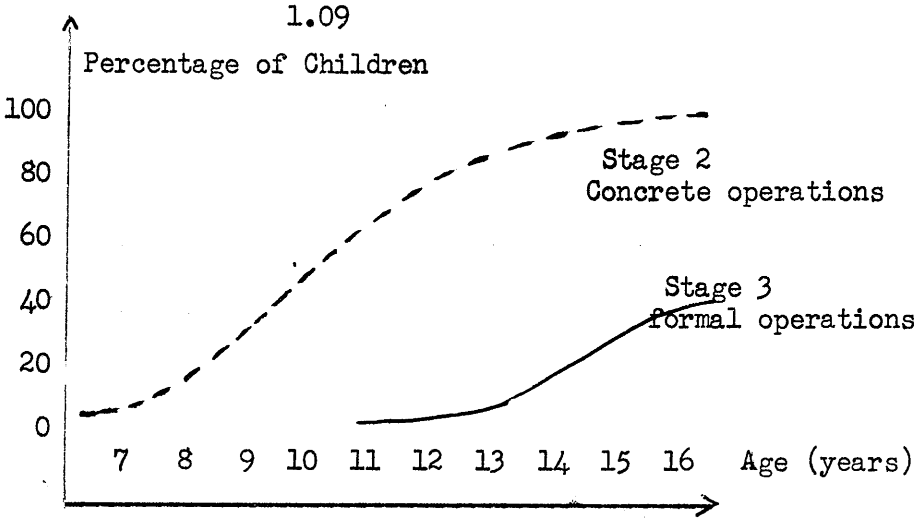
begin to emerge in early adolescence, according to Piaget.

However, Lovell maintains that

"this development takes place at 11-12 in outstanding pupils and from about 14 - 15 in ordinary ones, although perhaps rarely or never in the least able".

It must be remembered of course, that all development takes place over a period of time by the child 'internalising', and that therefore, many pupils will not have completed Piaget's stage 3 until late adolescence.

It is the 14 year olds' inability to elaborate second order relations in mathematics, as for proportion, which is the stumbling block for pupils in the quantitative calculations in many areas of chemistry, and there is some evidence (1) that this can persist up to University level. While Piaget puts the full capacity to deal with proportionality at between 14 & 15, Shayer reports (12) that in his experience this might well be a year or two below the average in this country. He estimates that we can expect 20% of the population to have reached this third stage by about 14 and only 3% at about 11.



It is only when the adolescent has reached this stage of formal operations that he can follow the form of an argument while disregarding its concrete content. In short he then reasons scientifically, forming hypotheses and testing them in reality and thought. Although a younger child's thought involves only concrete objects, the adolescent can imagine what might be possible. He can speculate, and his speculations are governed by logical rules.

With virtually the whole of sections H, I, J, and some of K of the S.C.E.E.B. 'O' grade syllabus(2) requiring thought at this stage 3 level(4) it is small wonder that pupils find difficulty with these topics when they are presented to them at the beginning of Class 3 (i.e. when approximately 14 years old).

It is difficult to see which more abstract thought patterns the writers of Papers No.7 (9) propose to introduce, yet still remaining within the confines of concrete operations.

Nomenclature

The use of formulae for the communication of chemical knowledge is fundamental to the practice of chemistry. The decision of I.U.P.A.C. in 1962 to standardise nomenclature was a major step forward for professional chemists. Its relevance for the lower echelons of school pupils is, however, debatable. In its wake there appeared various suggestions for the systematic naming of inorganic compounds and names such as 'potassium hexacyanato ferrate III' appeared on laboratory shelves. The Association for Science Education published in 1970 a draft of a paper on proposed nomenclature (13). Many of these names were highly illogical and were as unhelpful to a child learning chemistry as the system they were meant to replace. In fact many of the names were positively worse than those in every day use. At least these had the advantage of being in common use in industry, even if not always systematic. These ideas served only to make the understanding of formulae and nomenclature more dependent on Stage 3. thinking and hence less understandable to the majority of Class 3 pupils.

<u>Teacher Reaction</u>

As has been said above, many teachers opted for a "maximum always" approach and this led to the production of notes such as:-

(i)

<u>Associated ions in compounds</u>

Ionic compound	SOLID	IN SOLUTION	
Magnesium bromide	$Mg^{2+}_{(s)} + 2Br^{-}_{(s)}$ *	$Mg^{2+}_{(aq)} + 2Br^{-}_{(aq)}$	
Sodium hydroxide	$Na^{+}_{(s)} + OH^{-}_{(s)}$	$Na^{+}_{(aq)} + OH^{-}_{(aq)}$	
Hydrochloric acid		$H^{+}_{(aq)} + Cl^{-}_{(aq)}$	Dilute
Nitric Acid		$H^{+}_{(aq)} + NO_3^{-}{}_{(aq)}$	Acids
Sulphuric acid		$2H^{+}_{(aq)} + SO_4^{2-}{}_{(aq)}$	
Hydrochloric acid		$H^{+}_{(1)} + Cl^{-}_{(1)}$	Conc.
Nitric acid		$H^{+}_{(1)} + NO_3^{-}{}_{(1)}$	Acids. /
Sulphuric acid		$2H^{+}_{(1)} + SO_4^{2-}{}_{(1)}$**	

* some writers prefer $Mg^{2+}2Br^{-}_{(s)}$

** some teachers prefer $H_2SO_{4(1)}$

/ these are all ionic to different extents and (1) should differentiate the concentrated acids from the dilute acids (aq).

(ii)

Equations should now be written in the following final form e.g. for addition of a solid carbonate to dilute hydrochloric acid.

$$(2Na^{+} + CO_3^{=})_{(s)} + 2H^{+}_{(aq)} + 2Cl^{-}_{(aq)} \longrightarrow CO_{2(g)} + H_2O + 2Na^{+}_{(aq)} + 2Cl^{-}_{(aq)}$$

(iii)

Get the class to write some formulae e.g.

$(Na^{+} + Cl^{-})_{(s)}$, $(2K^{+} + S^{=})_{(s)}$, $(2Al^{+++} + 3O^{=})_{(s)}$.

The situation is aptly summed up by a college of Education Lecturer in Chemistry who wrote in 1969

"I do not think it is very important what one teaches on these points (formulae, state symbols, etc.) but for the pupils sake I think that all the Chemistry Staff in one school should teach the same system".

Summary

In 1970 the situation was a very confused one with on the one side, official publications apparently advocating complexity and on the other, some teachers becoming more disillusioned as they tried to teach these to their pupils.

If the theory proposed by Gagné,(14) the basis of which is, "that any piece of knowledge can only be acquired by people who possess certain prerequisite pieces of knowledge which have their own prerequisites in turn" (White(15)), is relevant for the teaching of formulae and equations, then in the light of the work of Piaget et al(6), it is not surprising that pupils find great difficulty in these topics.

CHAPTER 2

PHASE I - GAGNÉ STUDY AND ATTITUDE QUESTIONNAIRE

Introduction

Much stress has been placed in recent years on structural learning e.g. Curriculum Papers No.7. (9) The learner is seen as a logical thinker, progressing from one step to another in a fashion similar to Euclidean geometry. It had become evident from teaching ordinary mortals at the SIII and SIV level that many of them had not reached the level of conceptual development necessary to handle adequately the work on formulae, equations and calculations, especially those involving proportion. Many of these pupils then seemed to revert to straight learning and recall in what has been described as "parrot-fashion", with all its accompanying pit-falls.

Many teachers in trying to overcome this problem had devised various teaching schemes and formulae presentations of varying degrees of complexity. The fourteen different ways of writing calcium chloride produced at a recent conference (16) bear witness to the lengths of ingenuity to which teachers had been stretched. The conference was of the opinion that contrary to popular belief, these served only to make matters worse, being in the main too complicated for straight recall to give a reasonable degree of accuracy, and conceptually beyond most 14 year olds.

It has been the experience of those involved in the teaching of these topics, that a class can, on one day, seem to have grasped completely all the ideas, writing even the most complex formulae. However, on the next day, they perform abysmally even on the simplest test. Retention then, seems to be a major problem, especially with the academically less gifted children.

These problems needed examination on an organised basis. It was decided as a preliminary step, to test pupils from various schools using a step-wise Gagné apprcach. (14)

Experimental Design

(1) Construct a Gagné net for the steps involved in writing binary formulae e.g. (HCl CO_2 etc).

(2) Construct a structured test on Gagné lines to break down formula writing into sequential steps and see at what stages in the thought processes most difficulties occur.

(3) Analyse the results, compare them with the Gagné net and draw valid conclusions.

(4) Construct a questionnaire to test pupil and teacher ideas of difficulty among the topics of formula writing and equations.

(5) Analyse the results and correlate these subjective results with test results.

(6) Conduct a series of 1:1 interviews with pupils as they work through the structured test, in order to establish whether the Gagné net used in construction of the test, is in fact a fair representation of the steps followed by pupils when writing formulae.

Selection of Schools

To test these ideas a number of schools were approached to participate in a structured test. The schools chosen gave a fair representation of types of schools in Scotland, population distribution and about 500 pupils.

The following schools actually took part:-

School Number	School Type
1	6 year selective in Central Scotland.
2	6 year selective in developing industrial area.
3	6 year comprehensive in Glasgow overspill area with poor intake.
4	6 year Roman Catholic Comprehensive in Central Scotland,
5	6 year comprehensive in large city - with average intake.
6	6 year comprehensive in large city with good intake.
7	6 year comprehensive in rural area.

This gave a total of 513 pupils. No detailed information was available on the spread of abilities within the schools. The comments made are based on either personal judgement or consultation with the Principal Teacher of Chemistry concerned.

Construction of the Test

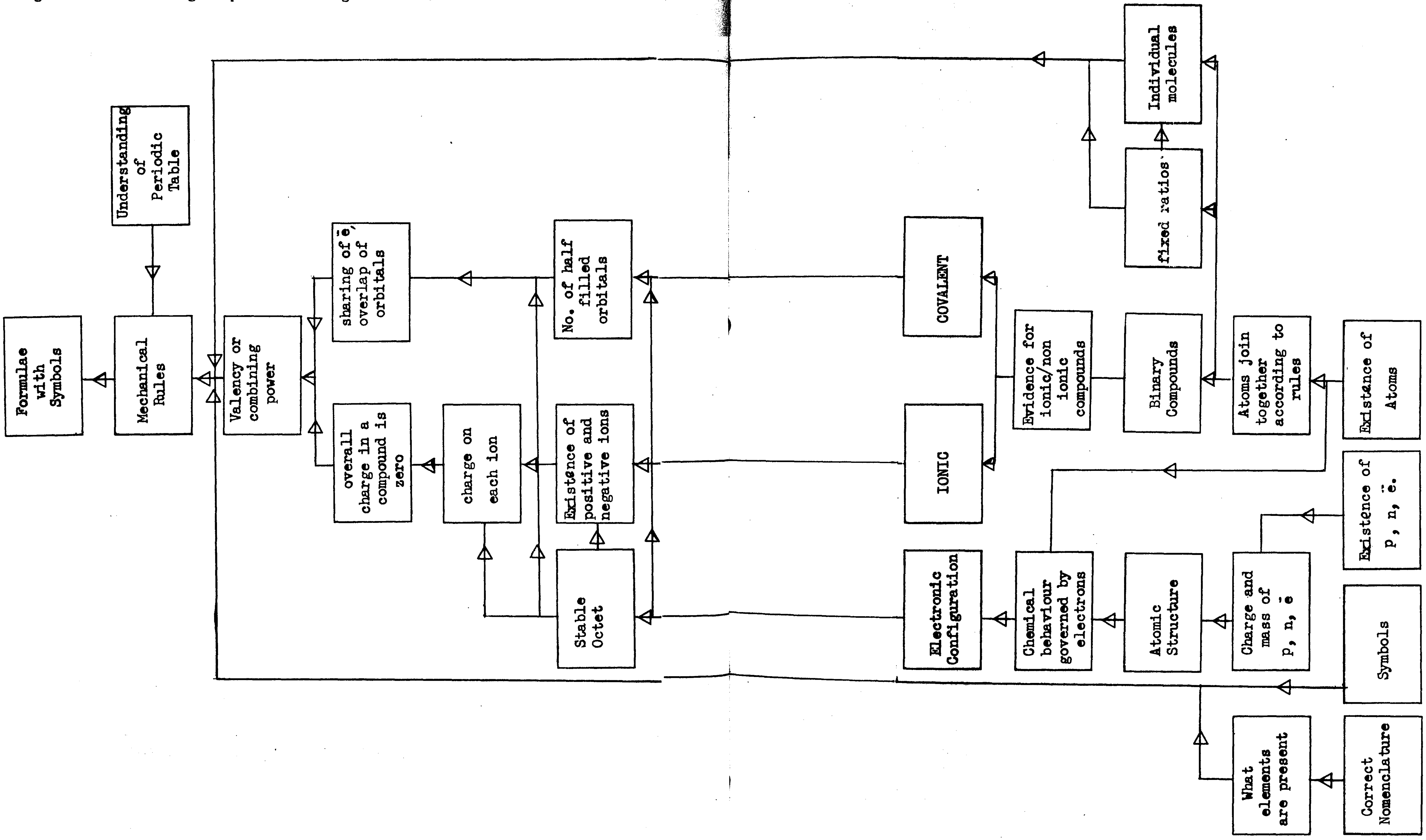
A Gagné type flow diagram was constructed for the learning steps involved in writing formulae. This is given in diagram 2.01.

The first 17 questions of the test were then constructed, structured so as to separate these learning steps. Questions 18-26 were added to investigate the pupils' grasp of the mole concept, equation writing and calculations arising from equations.

A rough draft was sent to schools for comment and modifications were made in the light of two suggestions received. The complete test is given in Appendix pages A.2.01 - A.2.04.

Diagram 2.01

Gagné net of learning steps for writing formulae.



Details of Test Construction

Although it would have made detailed examination of the results very much easier, an objective test type layout was rejected for two main reasons

(1) In a logical sequence each step should be dependent on all the previous steps.

(2) When the correct answer is provided it would be impossible to separate recall from recognition.

Where the object of the investigation was to test logical thinking, relevant data were provided, so as to cut down the amount of recall to a minimum.

Full details of the reasoning behind each question are given in the appendix pages A.2.05 - A.2.07.

Administration

Copies of the test were sent to schools in January/February 1971, to allow all the schools involved to have time to complete teaching of sections G, H, I, of the 'O' grade syllabus (2) and to have a few months for practice. All pupils following an S.C.E. Chemistry course in SIII were asked to complete the test with the help of a Periodic Table.

Checking and Correction

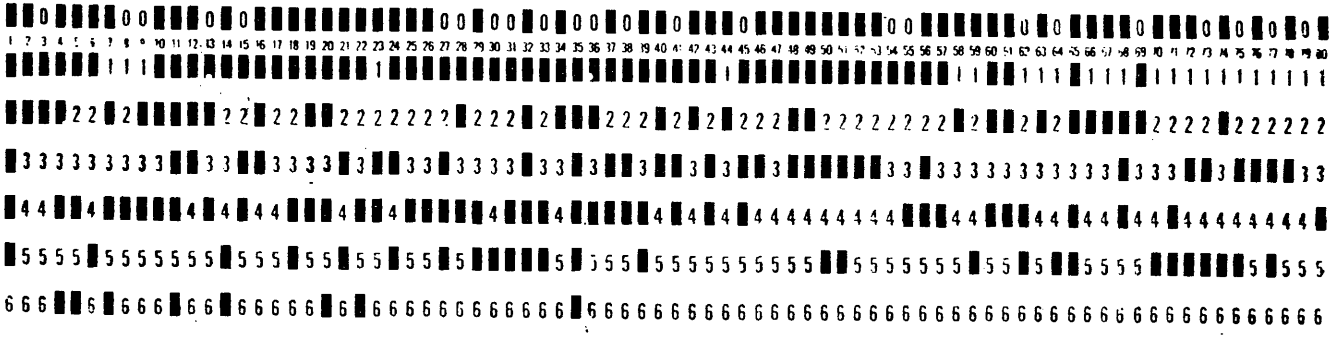
Teachers sent in the completed tests and they were numbered to make school identification easier. (These numbers are given in appendix A.2.08) They were then marked individually and the information transferred manually to punch cards. (The marking scheme is given in appendix p.A.2.08-A.2.09). One set of cards was punched, one card for each step, showing mistakes as holes, and a second set showing correct responses as holes.

By this method each pupil occupied the same position on each card and comparison between questions could be made by optically comparing the coincidences of holes between cards. See diagram 2.02 - 2.03.

DIAGRAM 2.02

SPECIMEN CARDS WITH HOLES PUNCHED FOR WRONG ANSWERS.

Quest. 13. Formula for Ca^{2+} wrong.



Quest. 14. Formula of $CaCl_2$ wrong.

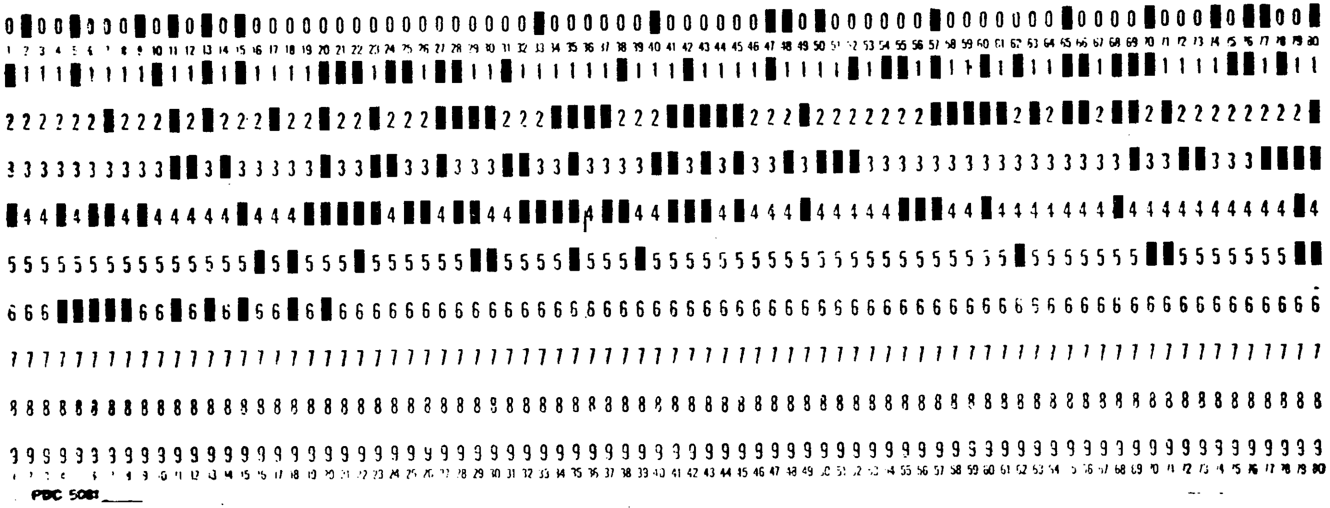
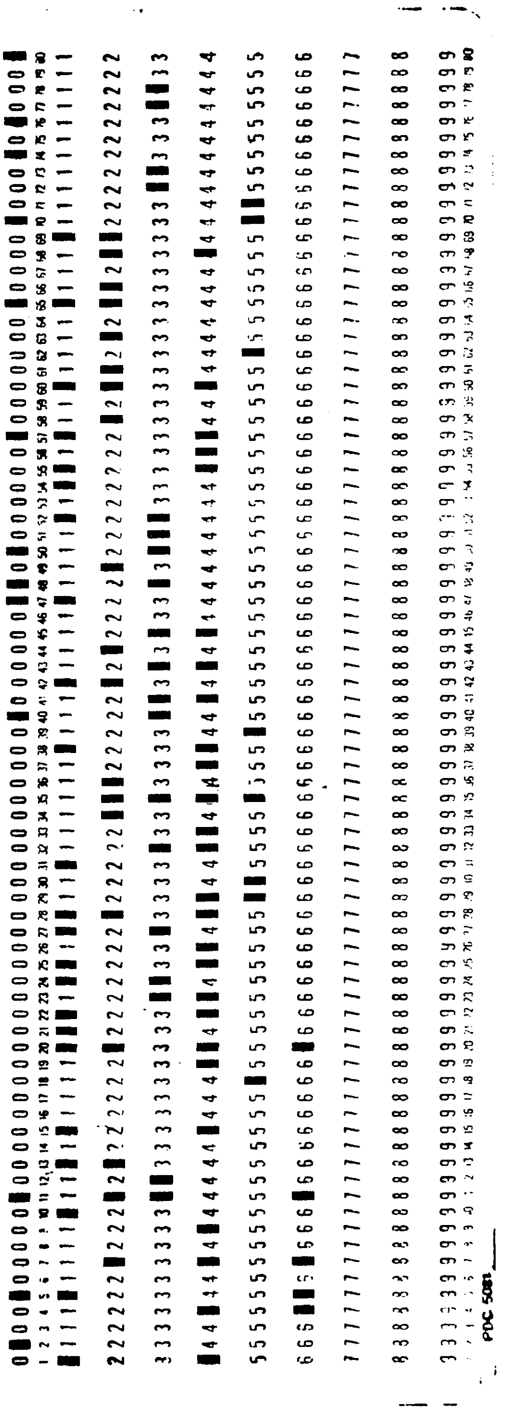


DIAGRAM 2.03

SPECIMEN CARD SHOWING THOSE WITH BOTH Ca^{2+} AND $CaCl_2$ WRONG

(achieved by overlapping cards 13 and 14.)



Results

Full details of results are given in appendix pages A.2.10 - A.2.14). Percentages quoted were calculated from the total population (513) unless otherwise stated (see appendix pages A.2.15 - A.2.16)

Correlations between cards (each one containing one item of information) were examined to try to establish the existance of logical thought patterns and the break-down points within these patterns, as outlined in the Gagné type flow diagram.

Whenever a question involved multiple answers, it seemed reasonable to make allowance for what might just be a slip in answering. However, it was also felt that competence should be shown by a reasonable level of accuracy. This level could not be constant for all questions because of the different numbers of responses within questions and was fixed as follows:-

Question	No. of Responses	Level of Acceptable Competence
1	3	2/3
5	4	3/4
6	4	3/4
7	4	3/4
8	4	3/4
15	4	3/4
16	5	3/5
17	1-4	3/4
18	4	3/4

Discussion of Results

1. Question 1,2 Ref. Numbers 1,2.

1. What are the three main particles in the atom?

2. Which of these is mainly responsible for chemical behaviour?

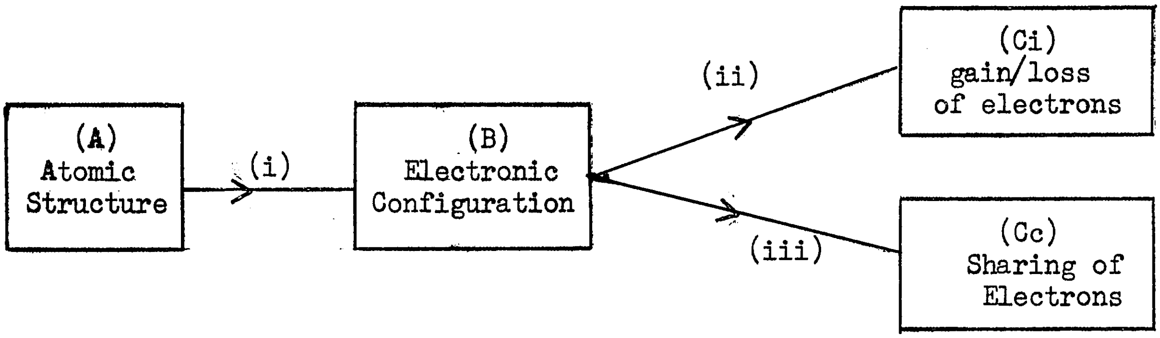
As expected pupils are competent in these basic recall questions.

2. Questions 3,4 Ref. Numbers 3-10.

3. The electron arrangement for $^{16}_{8}O$ is (a) 2.4.2. ☐
(b) 2.6 ☐
(tick the appropriate box) (c) 2.8.6. ☐
(d) 2.8.4.2 ☐

4. Atoms seem more stable when they have a completely filled outside level (shell) of electrons.

The $^{16}_{8}O$ atom might achieve this by ....two electrons with another oxygen atom or by .... two electrons altogether.



Step	%
(a) failed (i)	27
(b) failed (ii)	38
(c) failed (iii)	29
(d) failed (i) passed (ii)	63
(e) failed (i) passed (iii)	46 } % of (a)
(f) failed (i) passed (ii) & (iii)	37
(g) failed (ii) and (iii)	13 % of (b)

(a) This may be caused by a lack of real understanding of A causing misinterpretation of $^{16}_{8}O$

(b) - (e) The ionic path seems to be better understood, but any differences may be due to bad wording in Question 4.

(f) This may be due to efficient mechanical use of the Periodic Table. However, as only 57% of all pupils had both (ii) & (iii) correct, this is not functioning at an acceptable level.

3. Questions 5,6 Ref. Numbers 11-16; 81-83;

5. Complete the following table

Atom	Electron Arrangement	Valence No. (Valency)
$_1H$		
$_6C$		
$_8O$		
$_9F$		

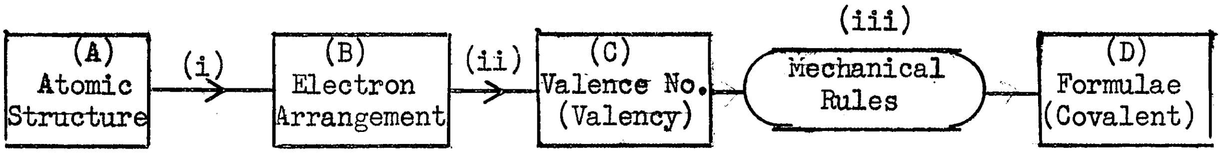
6. Using the information in the table above write the formulae for

(a) Hydrogen fluoride ....

(b) Carbon hydride ....

(c) Hydrogen oxide ....

(d) Carbon oxide ....



Step	%
(a) failed (i)	22
(b) failed (ii)	20
(c) failed (iii)	22
(d) failed (i) Passed (ii)	37 } % of (a)
(e) passed (i) (ii) & (iii)	35
(f) wrote formulae correctly	43
(g) method for formulae correct	20

(a) Approximately the same as in (2) above.

(d) This is probably due to mechanical use of the Periodic Table.

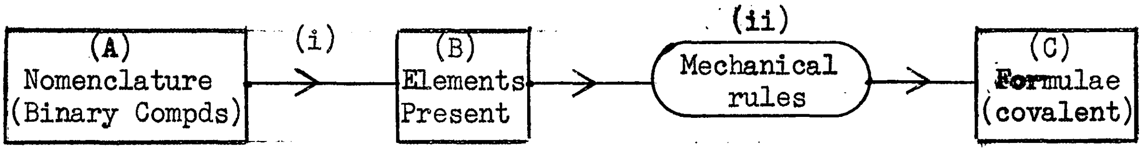
(e) (f) (g) As more pupils can write formulae correctly, or have the correct method, than managed steps (i), (ii) & (iii), it seems that most pupils rely on mechanically applying rules based on position in the Periodic Table. For 37% of pupils to be unable to apply these rules is, however, not an acceptable level of competence.

4. Questions 7,8. Ref. Numbers 17-25

7. What elements are present in each of the following compounds?

(a) Hydrogen sulphide ....
(b) Boron fluoride ....
(c) Phosphorus oxide ....
(d) Silicon hydride ....

8. With the help of a Periodic Table write the formulae for the four compounds in question (7).



Step	%
(a) failed (i)	30
(b) failed (i) because put in oxygen	75
(c) failed (ii)	67
(d) failed (ii) but had correct method	52

(a) & (b). It is not unnatural that pupils find difficulty in writing even binary formulae when so many can not correctly establish what elements are involved. When three quarters of these pupils have included oxygen, it is probable that the difficulty arises because of confusion with - ITE compounds.

(c) & (d). These levels of competence are unsatisfactory. Later work will show that before encumbering pupils with other more difficult compounds they could achieve a far higher pass rate in writing binary formulae.

It is surprising that 13 pupils managed step (ii) successfully but could not manage step (i). From the compounds used it would not appear that this is recall of known situations. The chance of non-validity of the test can not be overlooked of course.

5. Questions 9,10. Ref. Numbers 26-33.

9. If an atom loses or gains electrons, it will become a charged particle (an ion)

e.g. $_{11}\text{Na} \rightarrow {}_{11}\text{Na}^{+} + e^{-}$

2.8.1   2.8

Complete the following, by filling in the spaces marked with an *

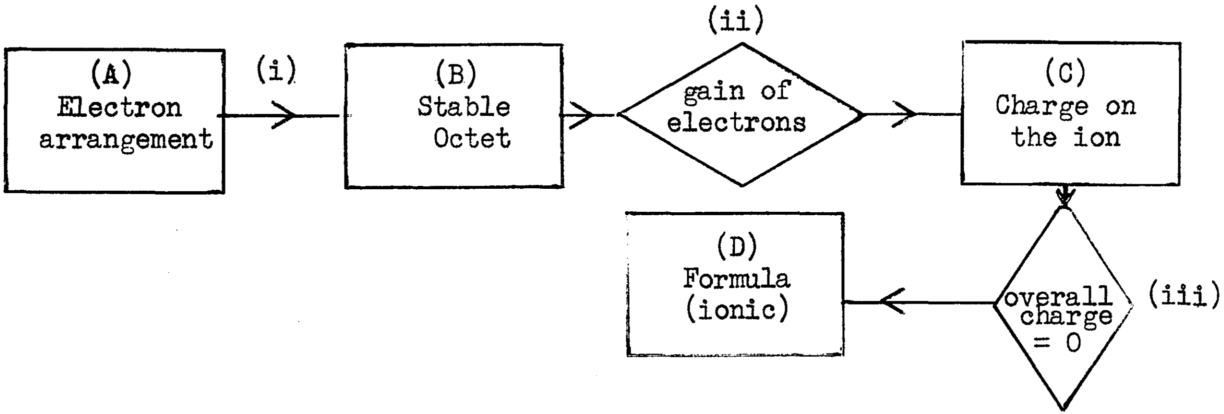
$_{17}\text{Cl} + \; * \rightarrow {}_{17}\text{Cl}*$

*   2.8.8

10. In an ordinary compound the total amount of positive charge will equal the total amount of negative charge - the overall charge will be zero.

e.g. the formula for lithium iodide $\text{Li}^{+}\text{I}^{-}$

The formula for sodium chloride is ....



Step	%
(a) managed to get C	48
(b) passed step (ii)	69
(c) passed step (ii) but failed to get C	40 % of (b)
(d) D correct	80
(e) D correct but C wrong	48 % of (d)

(a) This illustrates a fundamental lack of understanding of atomic structure.

(b) Presumably efficient mechanical use of the Periodic Table accounts for the extra 20%. Very few (38 pupils) managed to work out C correctly without step (ii). These are probably purely recall.

(c) Writing charges on even simple ions seems to present some difficulty.

(d) & (e) A high proportion of the correct answers to D must have been recall, which must also account for the 74% of those who had C wrong arriving at the correct answer to D.

6. <u>Questions 11-14 Ref. Numbers 34-47 : 84-87</u>

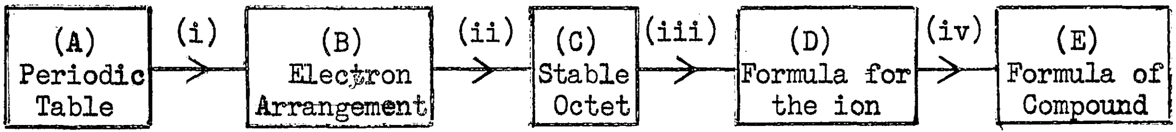
11. Calcium is in column two of the Periodic Table. Write down its electron arrangement.

$_{20}Ca$ ....

12. How many electrons will it lose to have a completely filled outside level (shell)? ....

13. Write down the symbol for the calcium ion ....

14. Write the formula for calcium chloride ....



Step	%
(a) failed (i)	22* (* each figure quoted as a % of the number successful at the previous step)
(b) failed (ii)	6*
(c) failed (iii)	44*
(d) failed (iv)	18*
(e) E correct but failed at least one of (i) - (iv)	52 % of E correct
(f) B wrong but (ii) correct	38 % of B wrong
(g) (ii) wrong but D. correct	27 % of (ii) wrong
(h) D wrong but E correct	56 % of D wrong

(a) - (d) As can be seen step (iii) was the most difficult. When 50% of pupils fail to arrive at D correctly it is not surprising that 30% of the total failed step (iv).

(e) - (h) For a significant number of pupils, failure at one step was no bar to success at the next. Certainly recall appears to function better at step (iv) level than at step (iii). A measure of this are the 22 pupils who had step (i - iv) all incorrect and had E correct, and the 8 pupils who had the previous two questions wrong as well and still had E correct.

It is apparent that pupils find the concept of a positive ion forming by losing negative particles particularly difficult.

These results might reasonably be interpreted as recall of a familiar situation rather than a basic fault in the Gagné net.

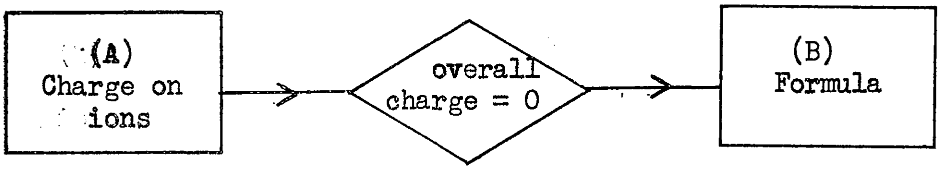
7. Question 15 Ref. Numbers 48,49.

15. By balancing the charges write the formulae for the compounds named. USE WORDS AND NOT SYMBOLS.

(Magnesium^{2+}) (Sulphate^{2-})
(Potassium^{+}) (Nitrate^{-})
(Sodium^{+}) (Oxide^{2-})

The first one has been done for you

(a) Sodium Oxide (Sodium^{+})$_2$ (Oxide^{2-})
(b) Magnesium Sulphate ....
(c) Magnesium Nitrate ....
(d) Potassium Sulphate ....
(e) Potassium Nitrate ....



37% of pupils could not carry out this operation. This may be due to the fact that they had not met questions of this type before. It is significant however, that 83% of those who failed did not use the correct method i.e. balancing charges - which means that pupils either understood the idea behind the question and completed it successfully or they failed to understand the mechanical process of balancing charges. Very few (33) made errors in execution.

8. <u>Questions 16, 17 Ref. Numbers 50-55</u>.

16. Write the formulae for the following ions, giving the charge (and hence the valence number (valency)) for each ion.

e.g. Iodide (I^-)

(a) Carbonate ....

(b) Sulphate ....

(c) Hydroxide ....

(d) Nitrate ....

(e) Ammonium ....

17. Using your answers to questions (16) write the full formulae for the following. (It is NOT essential to give the charge on each ion),

e.g. Potassium Iodide KI

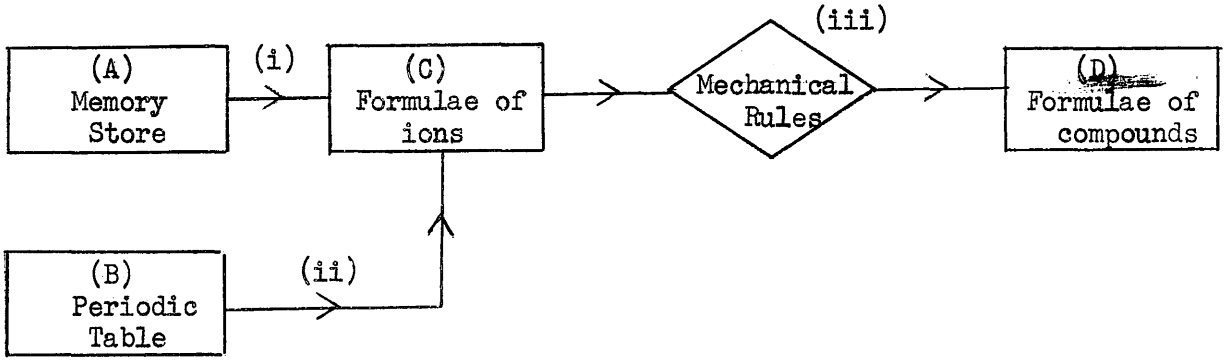
(a) Potassium sulphate ....

(b) Magnesium nitrate ....

(c) Ammonium carbonate ....

(d) Iron (III) hydroxide ....

(e) Sodium silicate ....



Step	%
(a) passed (i)	50
(b) passed (i), failed (iii)	50 (of (a))
(c) C wrong but correct method for (iii)	17 % of C wrong

(a) This major hurdle has now been removed by the provision of a table of oxyanions in the data book supplied for S.C.E. Examinations (21) in and after 1973.

(b) That only 25% of pupils can proceed both logically and correctly for all the steps involved is disturbing. That some of the formulae were obtained by recall is apparent (15 pupils had C wrong and D correct).

(c) Again it is disturbing that so few had the correct method here.

9. Question 17(e) Ref. Numbers 56-58

17 (e) Write the formula for sodium silicate.

Na_2SiO_3 correct = 4% (23 pupils)

Na_2SiO_3 correct by recall = 6 pupils

Misunderstanding of nomenclature (i.e. left out oxygen) = 68%

If formulae writing is based on proper understanding then extrapolation to unknown ions and compounds should be relatively easy. The figures above are indicative of the state of understanding behind formula writing at this level.

10. Questions 18-19 Ref. Numbers 59-62

18. The formula weight of a compound can be found by adding together the individual atomic weights.

e.g. NaI 23 + 127 → 150

Use the following list of atomic weights to calculate the atomic weight of the compounds (a-d).

Mg = 24; I = 127; B = 11; H = 1

K = 39; N = 14; O = 16.

(a) MgI_2 .... → ....

(b) B_2H_{10} .... → ....

(c) KNO_2 .... → ....

(d) $Mg(NO_2)_2$ .... → ....

19. How many moles (gram atoms) of iron are there in 1 mole of Fe_2O_3? ....

(a)	Could not calculate formulae weights (even when shown the method by example)	31%
(b)	failed because of arithmetical errors	12%
(c)	Do not understand the quantitative meaning of formulae.	19%
(d)	Failed when formula weight question is phrased in terms of moles.	68%
(e)	Had 18 correct but 19 wrong.	64% *

* percentage of those with F.Wt. method correct.

11. <u>Questions 20-22 Ref. Numbers 63-65</u>

20. A simple equation is a summary of what has happened in a chemical reaction. Write down in your own words what the following equation says.

$$Na + S \xrightarrow{heat} Na_2S$$

....

....

....

21. What is meant by the term 'Balanced Equation'?

....

....

22. When is it essential to write a balanced equation?

When 70% of pupils show inability to translate formulae into words should we in fact write equations using formulae, where words would suffice?

Many pupils do not, it seems, make the distinction outlined in Memorandum 7 (8) between "some" of a substance and "moles of a substance" from a balanced equation. Large numbers failed question 20 by including quantitative descriptions. And yet these pupils also show a lack of understanding as to the purpose of balanced equations, when 77% of them fail question 22. Many teachers insist on writing balanced equations all the time - for practice? - should we not write balanced equations <u>only</u> when necessary, to emphasise the quantitative nature?

12. <u>Question 23 Ref. Numbers 66-69</u>

23. Here is a balanced equation. Use it to answer the questions below.

$$2Pb(NO_3)_2 \xrightarrow{heat} 2PbO + 4NO_2 + O_2$$

(a) How many moles of NO_2 would you be able to get from 2 moles of $Pb(NO_3)_2$? ....

(b) How many moles of oxygen would you get from 1 mole of $Pb(NO_3)_2$? ....

The lack of understanding of the real meaning of a balanced equation is emphasised here when 80% of pupils failed to read a number directly from an equation. Perhaps the blank space meaning ONE, as in algebra, x means 1x, causes confusion.

When the concept of proportionality is introduced, the failure rate jumps to 97% - this being the worst for any question in the paper. Even of this small number correct 43% appear to have guessed the answer as they failed in the easier first part. 93% of those who passed the easy stage, failed on the proportionality.

13. <u>Question 24 Ref. Numbers 70-71</u>.

24. When chalk is roasted, carbon dioxide is produced.

$$CaCO_3 \xrightarrow{heat} CaO + CO_2$$

	$CaCO_3$	CaO + CO_2
formula weight	100	56 44

What weight of CO_2 would be made by completely roasting 15 g. of chalk?

This question which has had as much of the chemistry removed as possible, shows that 71% of pupils can not manage simple proportion calculations. This concept would appear to be either:-

(i) introduced too early

(ii) taught conflictingly by scientists and mathematicians

(iii) taught very badly.

The work of Piaget (6) would seem to confirm (i) but (ii) and (iii) are at present under investigation. (17)

Question 23(b) wrong but 24 correct 29%

These pupils appear to have failed 23(b) because of chemical difficulties rather than mathematical ones. For 71% the problem, therefore, would appear to be mathematical.

14. <u>Question 25 Ref. Numbers 72-75</u>.

25. Balance the following equations

(a) $Ca(OH)_2 + HCl \longrightarrow CaCl_2 + H_2O$

(b) $Ca^{2+}_{(aq)} + 2Cl^-_{(aq)} + Ag^+_{(aq)} + NO^-_{3(aq)}$

$\longrightarrow Ca^{2+}_{(aq)} + 2NO^-_{3(aq)} + Ag^+Cl^-_{(s)}$

It would appear that pupils found an ionically written equation slightly easier to balance, but this question was very much school biased (see Ref. Numbers 72,73).

Pupils who had balanced a 'covalent' type equation correctly could 'extrapolate' to an ionic equation slightly better than vice-versa, although this again was school biased (see Ref. Numbers 73,74.).

15. Question 26 Ref. Numbers 76-80

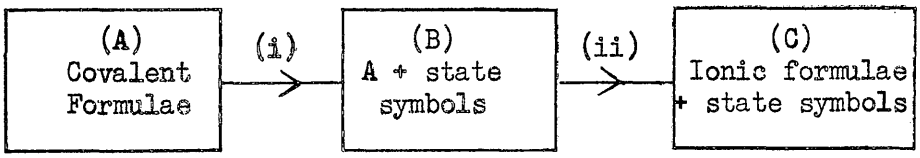
26. A pupil wrote the following sentences in his note-book. Rewrite them using no symbols.

(a) He sprinkled NaCl into a beaker full of H_2O.

(b) $H_2O_{(l)}$ and $Mg_{(s)}$ do not react readily to give $H_{2(g)}$ but when $H_2O_{(g)}$ is passed over hot $Mg_{(s)}$ it gives $H_{2(g)}$ and $MgO_{(s)}$.

(c) $Ag^+_{(aq)}$ + $NO^-_{3(aq)}$ were added to $H^+_{(aq)}$ + $Cl^-_{(aq)}$ to give $Ag^+Cl^-_{(s)}$ + $H^+_{(aq)}$ + $NO^-_{3(aq)}$.

Memorandum No. 7 (8) recommends the use of formulae as "shorthand" for names. It is evident that pupils are far more facile with covalently written formulae, and that state symbols convey little useful information. It would be more effective to write "steam" and not $H_2O_{(g)}$.



Step (i)	50% failed
Step (ii)	further 30% failed

The unnecessary use of state symbols and ionic formulae must be questioned at these levels of competence. That only 5% of pupils can interpret $Ag^+_{(aq)}$ + $NO^-_{3(aq)}$ correctly is condemnation enough of over-complication for no good reason.

Attitude Questionnaire (Phase I)

At the same time that pupils completed the structured test, they also filled in a questionnaire to estimate how difficult they found parts of the course. Staff were asked to fill in a similar one, giving two responses for each question - one for how difficult they thought pupils found the topics to learn, and the second for how difficult they found them to teach.

Copies of the questionnaires are given in Appendix pages A.2.17 - A.2.18

Analysis of Questionnaires

The responses were given numerical values as follows:-

Responses	Numerical Factor
Very Easy	1
Easy	2
Hard	3
Very Hard	4

The responses for each question were then totalled, multiplied by the respective numerical factor, summed and averaged. These averages were then multiplied by 20, giving a range of scores from 20 to 80, median 50, as an indication of the level of difficulty found. (SeeAppendix Page A.2.53.)

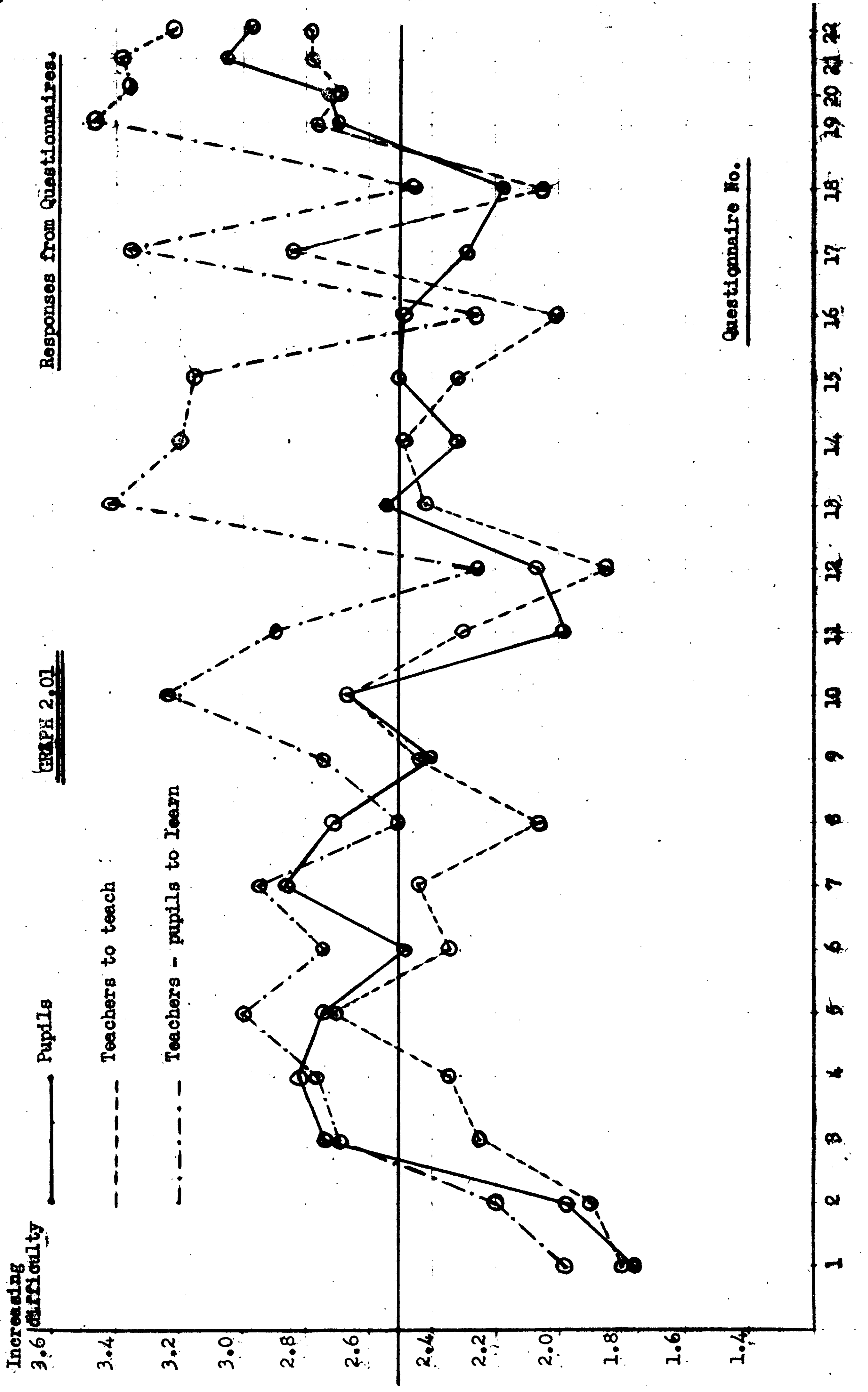
Results from Questionnaire

Final results are tabulated in Appendix pages A.2.19-A.2.20. From this data graphs were drawn showing:-

(i) Pupils idea of difficulty
Teachers idea of difficulty to teach
Teachers idea of difficulty for pupils to learn.

(ii) Pupils idea of difficulty
actual performance in the test.

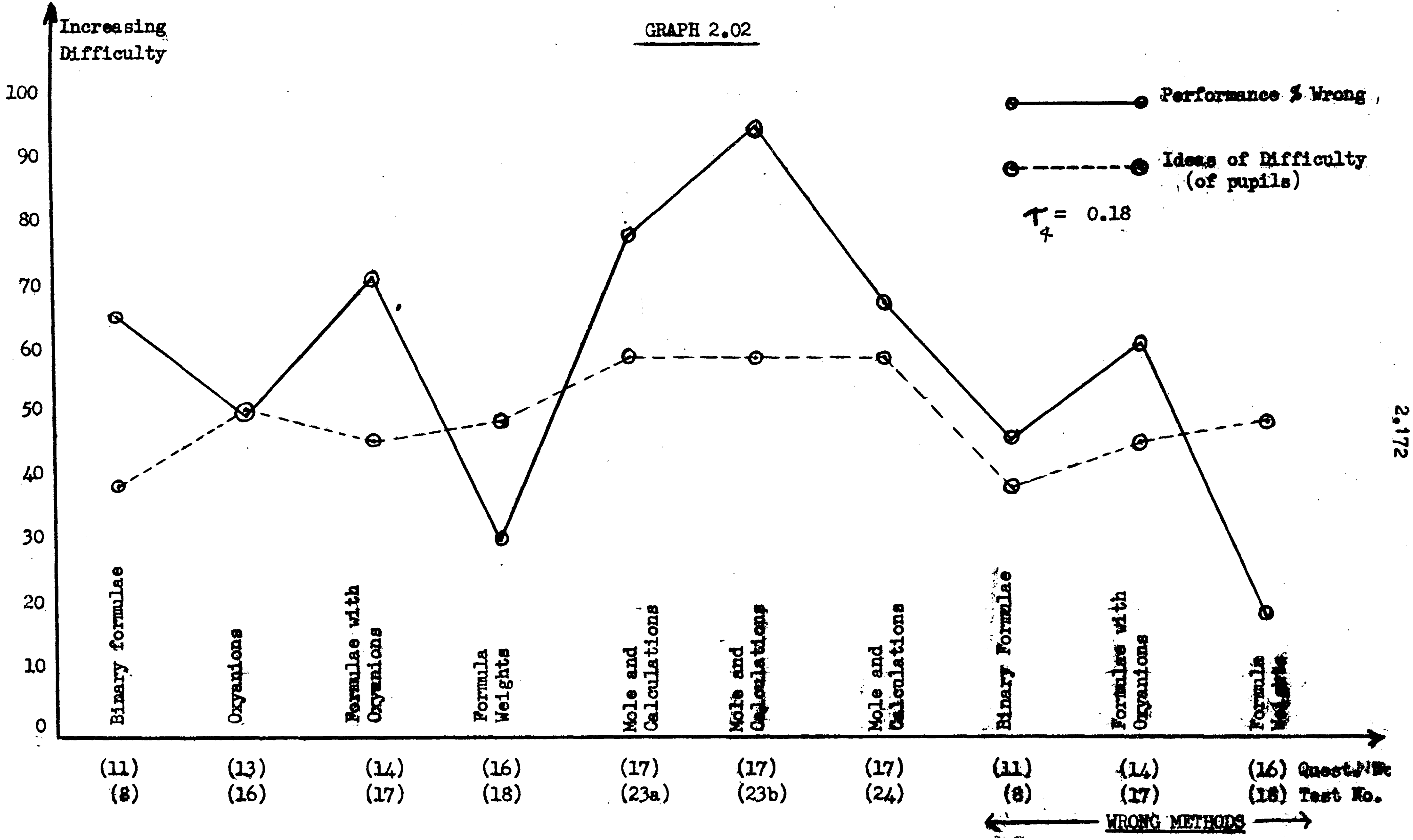
(iii) Teachers idea of difficulty for pupils to learn
Performance in the test.

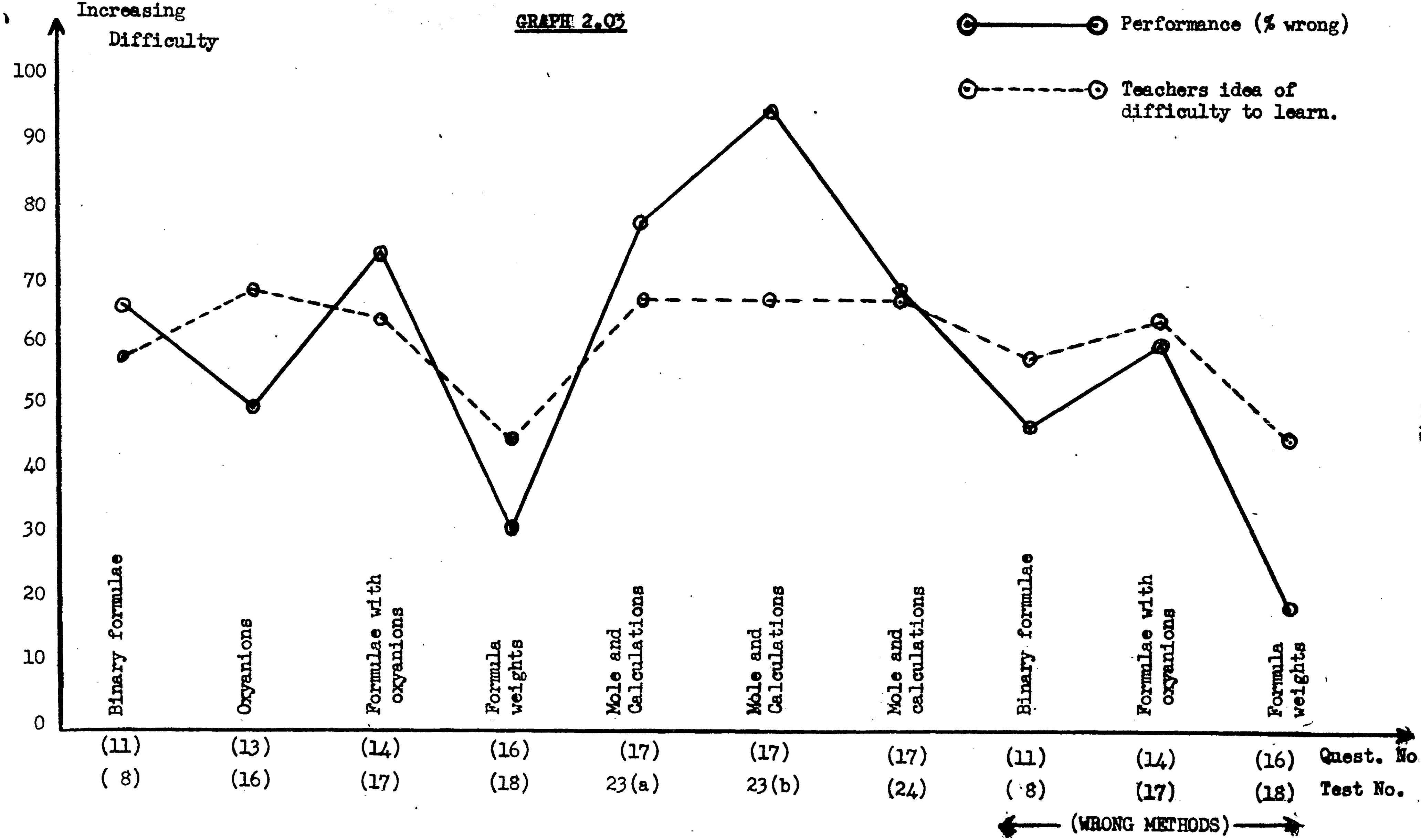


GRAPH 2.01

Responses from Questionnaires.

GRAPH 2.02


Increasing Difficulty
100
90
80
70
60
50
40
30
20
10
0
Performance % Wrong
Ideas of Difficulty (of pupils)
$\tau_4 = 0.18$
Binary formulae
Oxyanions
Formulae with Oxyanions
Formula Weights
Mole and Calculations
Mole and Calculations
Mole and Calculations
Binary Formulae
Formulae with Oxyanions
Formula Weights
(11) (8)
(13) (16)
(14) (17)
(16) (18)
(17) (23a)
(17) (23b)
(17) (24)
(11) (8)
(14) (17)
(16) (18)
Quest. No.
Test No.
WRONG METHODS



GRAPH 2.03

Increasing Difficulty
100
90
80
70
60
50
40
30
20
10
0
Performance (% wrong)
Teachers idea of difficulty to learn.
Binary formulae
Oxyanions
Formulae with oxyanions
Formula weights
Mole and Calculations
Mole and Calculations
Mole and calculations
Binary formulae
Formulae with oxyanions
Formula weights
(11)
(13)
(14)
(16)
(17)
(17)
(17)
(11)
(14)
(16)
Quest. No
(8)
(16)
(17)
(18)
23(a)
23(b)
(24)
(8)
(17)
(18)
Test No.
(WRONG METHODS)

These are shown in graphs 2.01 - 2.03.

Discussion of Results

(i) Teachers generally found these topics easier to teach than the pupils found them to learn.

(ii) Teachers' estimate of how difficult the pupils found these topics to learn was generally higher than the pupils own estimate.

(iii) Pupils thought that writing formulae was not so difficult to learn while teachers thought this would be more difficult.

(iv) Pupils did not seem to show any special bias towards covalent or ionic ideas.

The following correlation coefficients were calculated using *

$$r = \frac{\sum xy - \sum x \sum y}{\sqrt{\left(\sum x^2 - \frac{(\sum x)^2}{n}\right)\left(\sum y^2 - \frac{(\sum y)^2}{n}\right)}}$$

r_1 (pupil response v teachers 'to teach') = 0.73

r_2 (pupil response v teachers 'pupils to learn') = 0.65

r_3 (teachers 'to teach' v teachers 'pupils to learn') = 0.86

These good correlations highlight the apparent discrepancies at the following questions.

3, Isotopes

4, Mass spectrometer

8, Electrolysis and conductance by ionic compounds

9, sharing electrons, covalent bonds

11, Binary formulae

14, Formulae with oxyanions

16, Calculation of formula weights

17, The mole and calculations

19, Writing symbol equations.

* (See Appendix Page A.2.52.)

Pupils found 3, 4, 8, 16 more difficult than the teachers thought they did and found 11, 14, 17, 19 considerably easier.

The correlation r_4 of only 0.18 between pupil estimate and actual performance in the test (questions 8, 16, 17, 18, 23, 24) was disappointing. Teachers, correlation r_5 0.70, had a more consistent estimate of difficulty. The calculation of formula weights appears to cause far less difficulty than anyone estimated. It is perhaps significant that those areas which have caused most problems, viz. formulae, equation writing, mole calculations, were all severely underestimated by pupils. This would tend to suggest that individually these do not present too high a hurdle for pupils to surmount, but that concentrated into a relatively short period of time, this hurdle is well nigh insurmountable by the average pupil in Class 3.

Alternatively, it could be that each step is essentially easy but it is the sequence of steps that is the cause of the trouble.

Re-run of Test.

Some teachers expressed the view that the test itself, mainly because it was too long, was the main cause of the poor performance recorded.

In order to help try to establish the validity of the test, it was decided to run part of the test again, using the same pupils as before, and setting the same standard of attainment.

Test Construction

It was decided to use the same items as in the first run of the test for

(1) Writing binary formulae
(2) formulae for "oxyanions"
(3) Writing formulae of 'ionic' compounds
(4) extrapolation to Na_2SiO_3
(5) Mole calculation from an equation

The full test is given in Appendix page A.2.21

Administration

The test was sent to schools in May, 1971. Results were received from schools 2, 3, 4, 5, 7.

Marking

This was in accordance with the details shown in Appendix page A.2.21. Ionic or covalent forms were taken as correct.

Results

Full details are tabulated in Appendix page A.2.22 as well as details from the first test run.

Graphs were drawn of % correct response against question number in both tests for

(1) Total schools 2, 3, 4, 5, 7, for Test 1 and the re-run, and showing performance of the whole group (schools 1-7) on test 1 for comparison.

(2) Each individual schools performance on the re-run.

These are given in graphs 2.04, 2.05. Product moment correlations were calculated as before.

r_6 (test 1 score v. Re-run score) schools 2, 3, 4, 5, 7 = 0.81

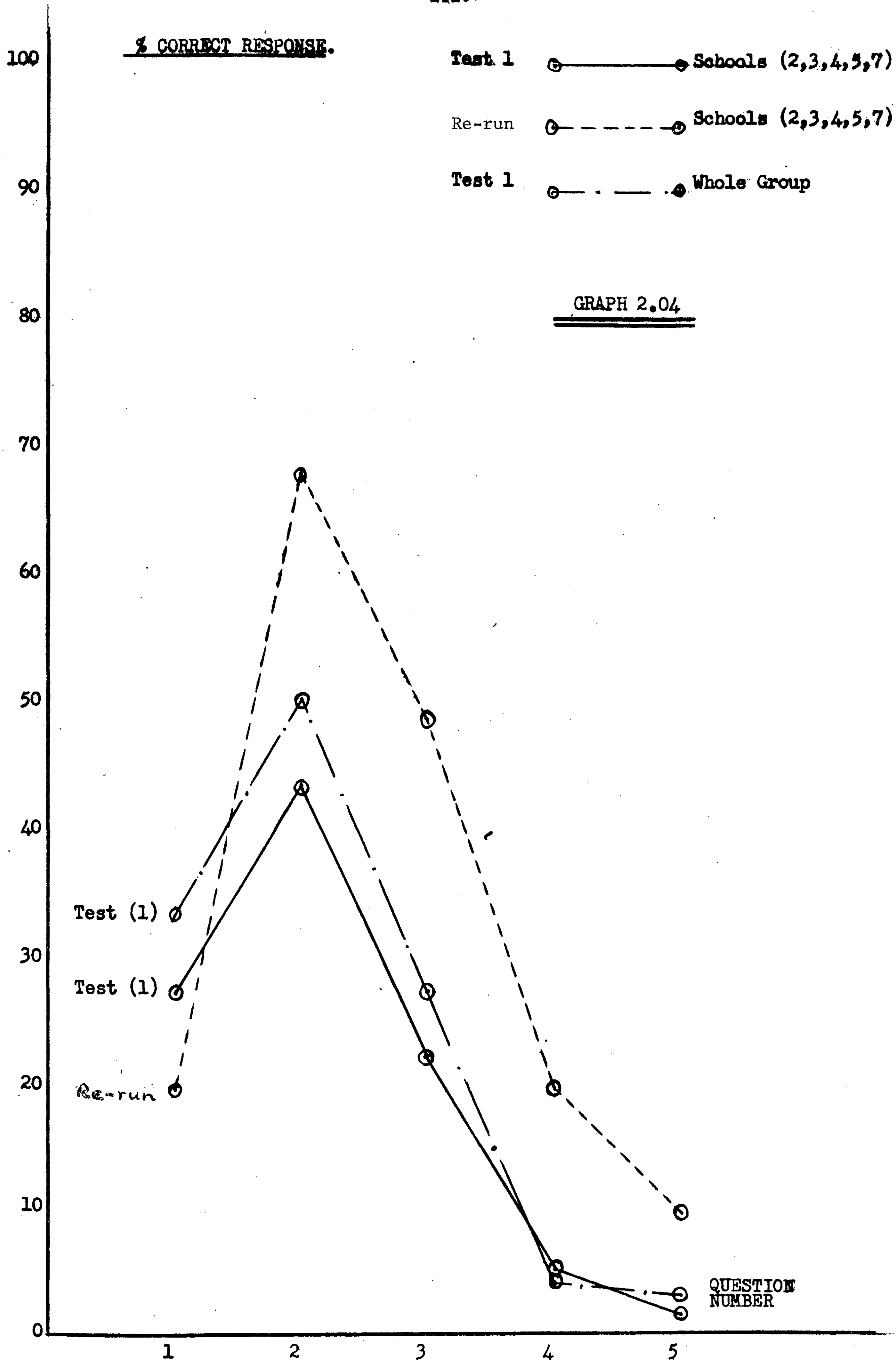
r_7 (test 1 score schools 2, 3, 4, 5, 7, v test 1 score schools 1 - 7) = 0.74

Discussion of Results

As pupils were now a little more mature, and would be seeing the questions for the second time, it was expected that performances would improve overall.

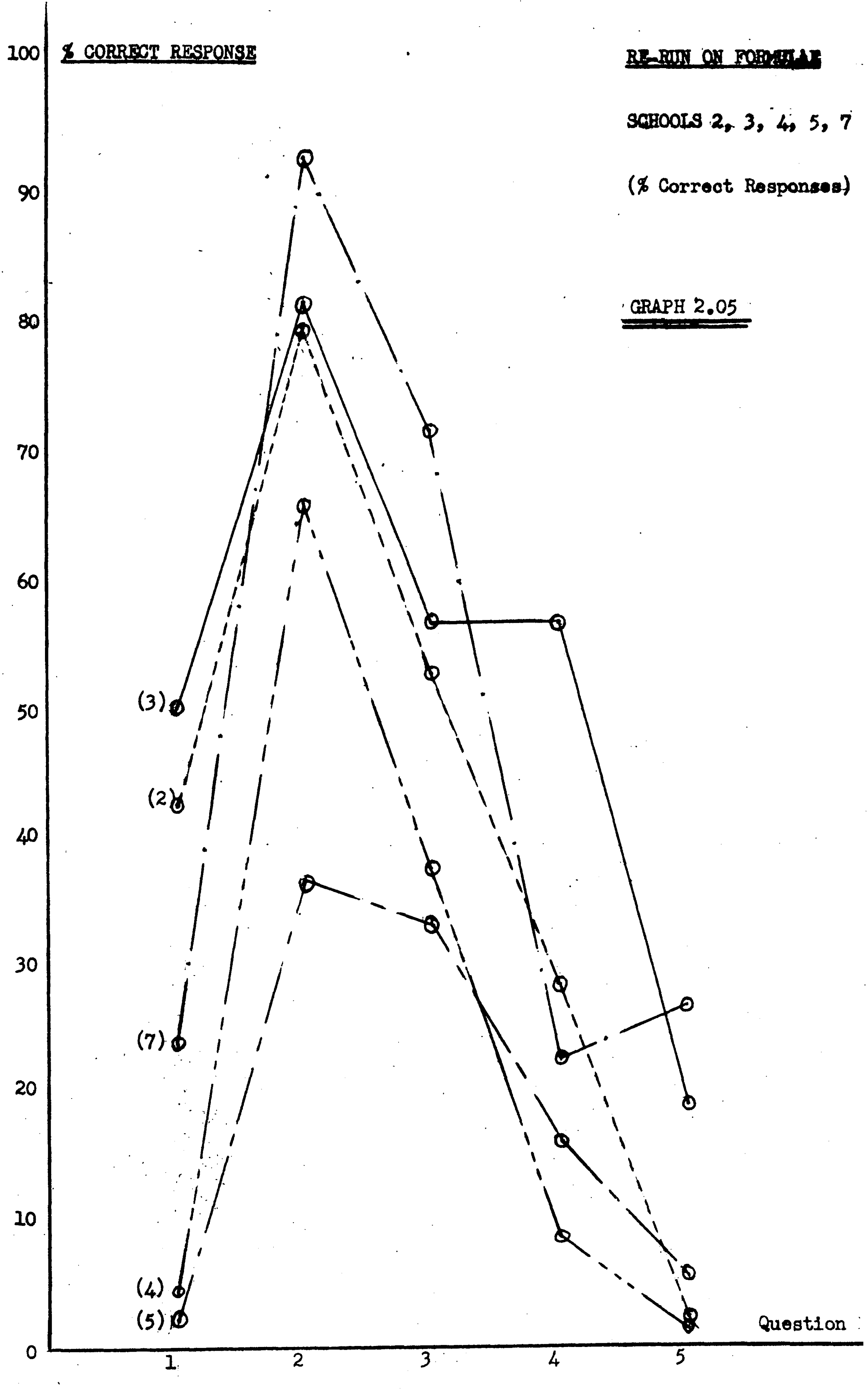
They did in fact improve reasonably evenly (r_6 = 0.81) except notably on what might be considered the easiest question, that of binary formulae. Teachers comments suggest the main reason for failure was the inclusion of oxygen in these -ide compounds.

Pupils are certainly more capable in this small, less stressing test, of remembering correct formulae for oxyanions, but this 68% recall level does not, it appears, lead to a satisfactory level



GRAPH 2.04

% CORRECT RESPONSE.
Test 1 — Schools (2,3,4,5,7)
Re-run — Schools (2,3,4,5,7)
Test 1 — Whole Group
100
90
80
70
60
50
40
30
20
10
0
Test (1)
Test (1)
Re-run
QUESTION NUMBER
1
2
3
4
5



RE-RUN ON FORMULAE

SCHOOLS 2, 3, 4, 5, 7

(% Correct Responses)

GRAPH 2.05

of competence in formula writing (49%).

Although more pupils can now extrapolate to Na_2SiO_3 the response level of only 19% probably includes an increased number of recall answers. The 'mole' problem is still a closed book for all but 10% of the population under test.

The smaller group of schools (2, 3, 4, 5, 7,) who completed run No.2, although scoring less on average in Test No.1 than the whole group average, correlate highly with that group, (Correlation calculated as average score for schools 2, 3, 4, 5, 7, v. average score for whole group for each item.) (r_7 = 0.74) and therefore can be taken as representative of it. Allowing for a possible overall increase in performance if the whole 7 schools had completed test 1 run No2 these levels of competence are still far from satisfactory.

Validation of the Gagné Net

Although validation of the Gagné net would in many ways be beside the point, since the net was constructed to represent the logical schema which teachers tend to assume, the criticism could be raised that using the techniques of anonymous test and mass statistical analysis does not allow any comment upon the thought processes of any pupil or group of pupils on the grounds that the logical steps proposed in the Gagné net need not correspond to the logical steps followed by any individual. A study was therefore necessary to establish whether the Gagné net composed using those logical steps assumed by a large proportion of teachers and which had been used in the construction of the test, was in fact a fair representation of the steps followed by pupils when writing formulae.

Experimental Method

A small group of pupils were interviewed individually while they sat relevant questions from Test 1. (See pages A.2.01 - A.2.04). Questions were asked to elucidate their thought processes while completing these questions i.e. to hear these out loud instead of being dependent on misunderstandings built into the test. The entire interviews were tape-recorded and transcribed later. The results were analysed for differences from or similarity to these steps in the Gagné net.

Choice of Pupils

Pupils were chosen

(1) to give an overall spread of ability in chemistry. This also gave a spread in V.R.Q. of 115 - 95.

(2) from Class 3 and Class 4 to see whether any maturity difference would be discernable.

These pupils were then arranged in order of merit based on performance in chemistry at school level, and given a reference number from 1 for the most able to 12 for the least able. Pupils 1 - 7 would be "above the red line" in presentation for 'O' grade in chemistry.

Conduct of the Interview

Each pupil was allowed to proceed through questions 5-14 and 16-17 of the test (see pages A.2.01 - A.2.03) at their own pace. The periodic table was provided for questions 8-17. Pupils 6, 8, 11 (Class 3) did not attempt questions 16-17 as they had not yet dealt with oxyanions in the 'O' grade course. Questions were asked

(i) to make certain of the method or thought processes used to achieve the answer,

(ii) relevant to any mistakes that had been made in order to find out where in the thought processes the mistake had occurred and where any possible barrier existed in these processes.

The pupils were encouraged to think aloud while answering the questions in the test and supplementary oral questions were only asked to clarify a particular point where a mistake had occurred.

The order of interview of the pupils was random.

Results

An edited transcript of each interview is given in the appendix pages A.2.23 to A.2.51. The transcript has been arranged so that for each question from the test the pupil's replies are given in the order 1-12. Supplementary questions or other essential information are shown in brackets. The tests were marked according to the scheme used previously (see Appendix A.2.08 - A.2.09). A table was drawn up showing the performance of each pupil, a tick representing success and a cross failure in that particular question. This is shown as Table 2.01. on page 2.24.

Ref. No.	Question	Pupil											
		1	2	3	4	5	6*	7	8*	9	10	11*	12
1	electron arrangements from atomic numbers	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X
2	valence numbers from electron arrangements	✓	✓	✓	✓	✓	✓	X	?	X	X	X	X
3	binary formulae	✓	✓	✓	X	✓	✓	✓	X	X	X	X	X
4	method for binary formulae	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	elements present from nomenclature	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓
6	writing binary formulae using the periodic table	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	completing the equation $\underset{*}{Cl} + * \rightarrow \underset{2.8.8.}{Cl^{*}}$	✓	✓	✓	✓	✓	X	✓	X	X	X	X	X
8	formula for $Na^{+}Cl^{-}$	✓	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓
9	electron arrangement for Ca	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	Calcium losing two electrons	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	formula for the calcium ion	✓	✓	✓	✓	✓	X	X	X	X	X	X	X
12	formula for $CaCl_2$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X
13	Charges on the ions in $CaCl_2$	✓	✓	✓	✓	?	X	X	X	X	X	X	X
14	formulae for oxyanions	✓	✓	✓	✓	✓	-	✓	-	✓	X	-	✓
15	charges on these oxyanions	✓	✓	X	X	✓	-	X	-	✓	X	-	X
16	formulae using oxyanions	✓	✓	✓	X	✓	-	✓	-	✓	X	-	X
17	method for writing formulae with oxyanions	✓	✓	✓	✓	✓	-	✓	-	✓	X	-	✓
18	extrapolation to Na_2SiO_3	✓	✓	✓	✓	✓	-	✓	-	✓	X	-	X
19	writing formulae by balancing charges	✓	✓	✓	✓	X	X	X	X	X	X	X	X

* Denotes third year pupil

Table 2.01

Analysis of Results

The completed, marked, tests and the transcript were examined in depth. It is to be noted that the general performance of the pupils interviewed was higher in certain areas than that found previously in the mass sample. (Pages A.2.10 - A.2.12)

Ref. number (Table 2.01)	% Success	
	Interviewed pupils	Previous Results
2	53	65
3	50	43
4	100	63
5	92	70
6	100	33
11	42	50
15	44	50
17	90	61

The pupils interviewed were far more facile with the 'mechanical rules' for formula writing (Ref. numbers 4, 5, 6, 17) but in questions which required reasoning through a sequence of steps (Ref. numbers 2, 3, 11, 15) their level of performance was similar to that observed with the mass sample. It is possible then that this small sample of pupils does not differ significantly from the mass sample tested as regards depth of understanding.

A summary of the salient points from the pupils' replies and tests, compiled by a process of distillation from the full transcripts is given below.

Ref. No.

(1) Most pupils had a good understanding of how to derive electron arrangements from the atomic number. Pupils 10, 11, 12, who did not seem to understand this procedure in question 5 were able to write the electron arrangement for calcium in question 11 and to reason correctly when they were using the periodic table. It is possible that for these pupils there is a lack of

(i) real understanding

and (ii) the ability to reason through a series of steps but that this has been covered by the fact that the periodic table provided the initiator for a process of recall.

(2) Pupils 1 - 6, 8, all appeared to be able to reason through correctly from electron arrangement to valence number and showed understanding of what was the physical significance of valency. The remainder did not appear to understand this. Two used the number of electrons in the outer level, two were relying on using the periodic table and could not work it out without this. These poorer pupils appeared to be applying rote-learned rules without understanding and did not appreciate when they had made errors even when these were pointed out.

(3) All pupils had a correct method for writing binary formulae.

Ref. No.

(3) Pupils 7, 10, 11, 12 were all relying on position in the periodic table and consequently, not having one, wrote wrong formulae when their memory was at fault.

(5) Only pupils 6, 8, 11 (all of Class 3) were confused over the -IDE ending but only No.6 included oxygen.

(6) All pupils could write binary formulae correctly using the periodic table and were all using a set of rules
namely (i) Write down the symbols
(ii) Write down the valencies using the positions of the elements in the periodic table
(iii) 'Cross-multiply' or 'flip-over' or 'change round'.

Pupil 2 appeared to understand the physical significance of these rules while the rest used them as a means to an end.

(7) The concepts behind ion formation seemed particularly difficult for the poorer pupils. The reasoning offered by these pupils showed a complete lack of understanding and the inability to reason in a coherent sequence of steps.

(8) Only pupil 8 had the formula Na^+Cl^- wrong and this because the answer given was Na^-Cl^-. However pupils 6, 8, 9, 10, 11, 12 did not appear to understand the significance of, or concepts behind, the charges on the ions. Only pupil 1 showed understanding of the overall balance of charges, but most could tie up valency with the number of positive or negative charges. Most pupils treated this as a separate question without relating it to what had been given above or in the previous question.

Ref. No.

(10) All pupils seemed to be able to work out why calcium should lose two electrons. Pupil 10 was able to argue logically back from an error.

(11) The concepts behind the formation of Ca^{2+} appeared beyond the grasp of pupils 6-12. They appeared to be recalling facts or rules and then applying them to the problem at hand regardless of applicability.

(12) Only pupil 12 did not write $CaCl_2$ correctly. Pupils 1-4 knew and understood the significance of the charges on the ions and ensured an overall neutrality. Pupils 5-12 mainly added charges as an afterthought having written the formula using the same rules as mentioned in (6) above, pupils 7-12 getting these wrong. Pupils 5-12 treated this question as a separate entity without referring at all to the previous questions, they were not reasoning through a sequence of logical steps but were applying rote-learned rules in isolation.

N.B. Pupils 6, 8, 11 are not included in the following.

(14) The formulae for oxyanions are rote-learned and committed to memory. Recall of the stoichiometry involved was good although the charges on the ions were confused by even the bright candidates. These however, tended to spot any mistakes and to correct them when writing formulae.

(16) Generally pupils could apply the 'rules' correctly although the poorer pupils tended to get more confused with the "cross-over" of combining powers than when writing binary formulae. Only pupil 1 used the idea of balancing charges.

Ref. No.

(16) The act of writing formulae seemed to trigger the recall of the formulae for oxyanions.

(18) All the pupils could extrapolate from CO_3^{2-} to SiO_3^{2-} except pupils 10,12 who attempted the problem as a binary compound.

Summary

(1) Pupils were very successful in those questions where rote-learned rules could be applied. Poorer pupils tended to apply these rules regardless of errors committed and tended not to recognise them even when pointed out.

(2) Poorer pupils could not cope with those questions which needed understanding (Understanding seemed to stop at about pupil 6-7) They seemed able to rote-learn a procedure but not to fully understand the reasoning steps behind the method e.g. the need for a periodic table to reason in questions 5 and 6. This is further evidenced by the fact that on an error being pointed out, they tended to reason in such a fashion as to embroil themselves further. In other words they coped well with questions involving Knowledge or Comprehension but could not deal with those involving Application or Higher Abilities. *

(3) When faced with an application step in a sequence most pupils tended to treat this as a separate entity without reference to what had preceeded it and applied learned rules i.e. Comprehension. This led to sequences such as:

(i) calcium will lose 2 electrons

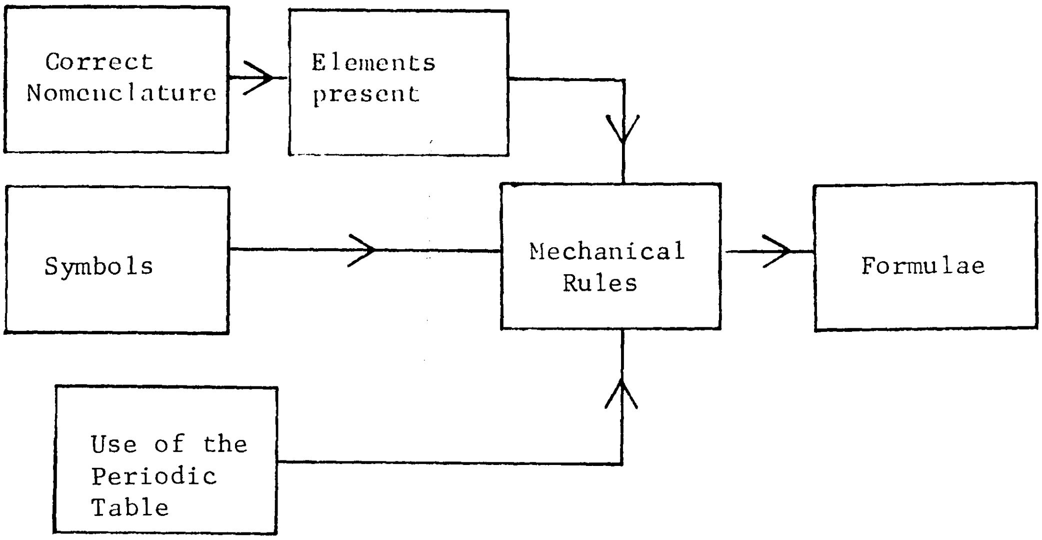
(ii) Ca^+

(iii) $CaCl_2$ or even $Ca^{2+}Cl_2^-$

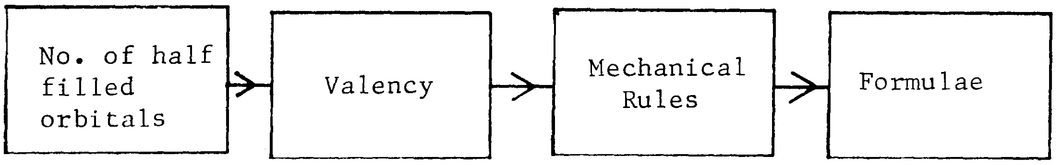
---

* These terms are used in the same sense as by Bloom (5)

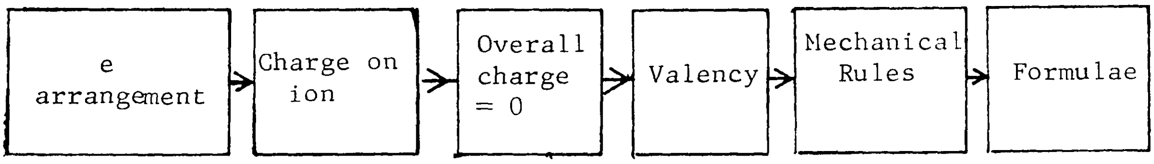
(4) All pupils used the pathway on the Gagné net as indicated by:-



(5) More able pupils reasoned through the steps.



(6) The most able pupils reasoned through the sequence



although they too used 'learned rules' possibly for speed and convenience.

(7) There did not appear to be any apparent maturity difference between the pupils in Class 3 and those in Class 4 except perhaps an increased readiness to say 'don't know' rather than to attempt something difficult.

(8) The Gagné net (Pages 2.031 0 2.032) appears to be a fair representation of the steps followed by able pupils writing formulae.

General Conclusions

(1) Pupils appear to use one or more of the routes shown in the Gagné net (Page 2.031 - 2.032) when writing formulae.

(2) Poor performance in test 1 was not primarily due to the length of the test and it appears to be a valid test.

(3) Poorer pupils do not appear to be able to reason at the understanding level. Rather they recall a learnt procedure and apply it in any situation.

(4) Pupils do not think through the complete logical sequence of steps when writing formulae, recall playing a large part. Thus when formulae of increasing complexity are used, recall becomes less efficient. Time must be given for a learnt procedure to develop with practice into a 'known' procedure.

(5) A large number of the mistakes in formula writing stem from a basic misunderstanding of nomenclature.

(6) The understanding of the formation of ions, i.e. losing electrons to become a positive ion, is a major obstacle.

(7) Pupils handle formulae of the type $CaCl_2$ better than those written with ionic charges. Although this is now strongly recommended,(18) pupils still have to be taught the ionic form to comply with"writing equations.... including ions in solution or in melts"(18)

(8) Increasing complexity leads to increased difficulties, not only with these more complex ideas, but also with those simpler ones learnt previously, and should only be introduced where absolutely necessary. We must remember that we are not training future chemists but educating children and if $CaCl_2$ will carry as much information as we require, we should not use $Ca^{2+}_{(aq)} + 2Cl^{-}_{(aq)}$.

(9) Individual formulae 'hurdles' in themselves do not pose too large a problem but do so when taught 'en bloc'.

(10) The 'mole' concept or more particularly calculations involving the mole concept and proportion, appear to be above the attainment level of the majority of third year pupils.

(11) Pupils do not understand what a chemical equation is saying. This arises from inability to translate formulae into words, and a lack of understanding of the 'mole' concept.

TEST 1.

1. What are the three main particles in the atom?

   (a) .... (b) .... (c) ....

2. Which of these is mainly responsible for chemical behaviour.

   ....

3. The electron arrangement for $^{16}_{8}O$ is (tick the appropriate box)

   (a) 2.4.2. ☐
   (b) 2.6 ☐
   (c) 2.8.6. ☐
   (d) 2.8.4.2. ☐

4. Atoms seem more stable when they have a completely filled outside level (shell) of electrons.

   The $^{16}_{8}O$ atom might achieve this by .... two electrons with another oxygen atom or by .... two electrons altogether.

5. Complete the following table

Atom	Electron Arrangement	Valence No. (Valency)
$_{1}H$		
$_{6}C$		
$_{8}O$		
$_{9}F$		

6. Using the information in the table above write the formulae for

   (a) Hydrogen fluoride ....
   (b) Carbon hydride ....
   (c) Hydrogen oxide ....
   (d) Carbon oxide ....

7. What elements are present in each of the following compounds?

   (a) Hydrogen sulphide ....
   (b) Boron fluoride ....
   (c) Phosphorus oxide ....
   (d) Silicon hydride ....

8. With the help of a Periodic Table write the formulae for the four compounds in question (7).

   (a) .... (b) ....
   (c) .... (d) ....

9. If an atom loses or gains electrons, it will become a charged particle (an ion)

e.g. $_{11}\mathrm{Na} \longrightarrow {}_{11}\mathrm{Na}^{+} + e^{-}$

2.8.1 2.8

Complete the following, by filling in the spaces marked with an *

$_{17}\mathrm{Cl} + * \longrightarrow {}_{17}\mathrm{Cl}^{*}$

* 2.8.8

10. In an ordinary compound the total amount of positive charge will equal the total amount of negative charge - the overall charge will be zero.

e.g. the formula for lithium iodide $\mathrm{Li}^{+}\mathrm{I}^{-}$

The formula for sodium chloride is ....

11. Calcium is in column two of the Periodic Table. Write down its electron arrangement.

$_{20}\mathrm{Ca}$ ....

12. How many electrons will it lose to have a completely filled outside level (shell)? ....

13. Write down the symbol for the calcium ion ....

14. Write the formula for calcium chloride ....

15. By balancing the charges write the formulae for the compounds named. USE WORDS AND NOT SYMBOLS.

$(\mathrm{Magnesium}^{2+})$ $(\mathrm{Sulphate}^{2-})$

$(\mathrm{Potassium}^{+})$ $(\mathrm{Nitrate}^{-})$

(Sodium^{+}) (Oxide^{2-})

The first one has been done for you

(a) Sodium Oxide $(\mathrm{Sodium}^{+})_2(\mathrm{Oxide}^{2-})$

(b) Magnesium Sulphate ....

(c) Magnesium Nitrate ....

(d) Potassium Sulphate ....

(e) Potassium Nitrate ....

16. Write the formulae for the following ions, giving the charge (and hence the valence number (valency) for each ion.

e.g. Iodide (I^{-})

(a) Carbonate ....

(b) Sulphate ....

(c) Hydroxide ....

(d) Nitrate ....

(e) Ammonium ....

17. Using your answers to question (16) write the full formulae for the following. (It is NOT essential to give the charge on each ion).

e.g. Potassium Iodide KI

(a) Potassium sulphate ....

(b) Magnesium nitrate ....

(c) Ammonium carbonate ....

(d) Iron (III) hydroxide ....

(e) Sodium silicate ....

18. The formula weight of a compound can be found by adding together the individual atomic weights.

e.g. $NaI \Longrightarrow 23 + 127 \Longrightarrow 150$

Use the following list of atomic weights to calculate the atomic weight of the compounds (a - d).

Mg = 24; I = 127; B = 11; H = 1;
K = 39; N = 14; O = 16.

(a) MgI_2 .... → ....

(b) B_2H_{10} .... → ....

(c) KNO_2 .... → ....

(d) $Mg(NO_2)_2$ .... → ....

19. How many moles (gram atoms) of iron are there in 1 mole of Fe_2O_3?

....

20. A simple equation is a summary of what has happened in a chemical reaction. Write down in your own words what the following equation says.

$$Na + S \xrightarrow{heat} Na_2S$$

....

....

....

21. What is meant by the term 'Balanced Equation'?

....

....

22. When is it essential to write a balanced equation?

....

23. Here is a balanced equation. Use it to answer the questions below.

$$2Pb(NO_3)_2 \xrightarrow{heat} 2\ PbO + 4NO_2 + O_2$$

(a) How many moles of NO_2 would you be able to get from 2 moles of $Pb(NO_3)_2$? ....

(b) How many moles of oxygen would you get from 1 mole of $Pb(NO_3)_2$? ....

24. When chalk is roasted, carbon dioxide is produced.

$$\begin{array}{lccc} & \mathrm{CaCO_3} & \xrightarrow{\text{heat}} & \mathrm{CaO} + \mathrm{CO_2} \\ \text{formula weight} & 100 & & 56 \quad 44 \end{array}$$

What weight of CO_2 would be made by completely roasting 15 g. of chalk.

25. Balance the following equations

(a) $Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$

(b) $Ca^{2+}_{(aq)} + 2Cl^{-}_{(aq)} + Ag^{+}_{(aq)} + NO^{-}_{3(aq)}$

$\rightarrow Ca^{2+}_{(aq)} + 2NO^{-}_{3(aq)} + Ag^{+}Cl^{-}_{(s)}$

26. A pupil wrote the following sentences in his note-book. Rewrite them using no symbols.

(a) He sprinkled NaCl into a beaker full of H_2O.

(b) $H_2O_{(l)}$ and $Mg_{(s)}$ do not react readily to give $H_{2(g)}$ but when $H_2O_{(g)}$ is passed over hot $Mg_{(s)}$ it gives $H_{2(g)}$ and $MgO_{(s)}$.

(c) $Ag^{+}_{(aq)} + NO^{-}_{3(aq)}$ were added to $H^{+}_{(aq)} + Cl^{-}_{(aq)}$ to give $Ag^{+}Cl^{-}_{(s)} + H^{+}_{(aq)} + NO^{-}_{3(aq)}$.

(a) ....

....

(b) ....

....

(c) ....

....

Details of reasoning behind test construction.

Question	Comment
1,2	Straight recall. Used as an easy starter into the test.
3	Calculation of electron arrangement - dependent on a knowledge of atomic structure.
4	To test the concept of a 'stable octet'. A typing error missed out "new" and included "altogether". This step dependent on 3.
5	To test knowledge of the connection between electron arrangement and valency.
6	To test knowledge of the "mechanical rules" for writing formulae, given the symbols, but dependent on 5. 5 and 6 together give basically the "covalent" path.
7	To test interpretation of nomenclature, especially the difference between - ide, ite, and ate endings.
8	To test knowledge of the "mechanical rules" - dependent on 7.
	Questions 9 - 17 investigate the "ionic" pathway.
9	Given a similar example, this is to test understanding of ion formation - how do positive and negative ions arise.
10	To test understanding of the reasoning behind the "mechanical rules" - dependent on 9.
11-13	The stepwise formation of the calcium ion, investigating understanding of electron arrangement, stable octet, formation of ions and the logical sequence of thought involved. Each step is dependent on the previous one.
14	A check on knowledge of the "mechanical rules". No pupil should, if thinking entirely logically, arrive at the correct answer if they have made a mistake in 11-13.

Question	Comment
15	Teachers have often asserted that pupils can easily learn and understand these mechanical rules for writing formulae, the biggest stumbling block being to remember the formulae of oxyanions, there being no appropriate way of logically working them out at their level of knowledge. If this is true, then when given all the necessary information, and not having to worry about the formulae of oxyanions, pupils should be able to write correct formulae.
16	Before May 1973, pupils had to remember the formulae of oxyanions in 'O' and 'H' grade exams. This question is testing the level of recall of the correct formulae.
17	This is to see (i) how well pupils can write formulae involving oxyanions, (ii) how much is based on recall, (iii) if pupils can extrapolate to an unknown situation.
18-19	To see whether pupils really understand the meaning of formulae in terms of atoms present.
20-25	Equation writing is dependent on correct formulae writing. S.C.E.E.B. marking schemes gave zero for any balanced equation in which there were incorrect formulae, and therefore, statistics provided by the S.C.E.E.B. on the knowledge of balancing equations probably only measure the ability to write formulae. These questions are to investigate the pupils understanding of a balanced equation.
20	To test the ability to translate formulae into meaningful chemical names.
21-22	To test basic understanding of the term "Balanced Equation"
23	(a) To test the understanding of the meaning of number prefixes in equations and the mole concept. (b) By using the same equation as in (a) we can now test the understanding of proportion - the figures being simple.

Question	Comment
24	By reducing the chemistry content as much as possible, this question has been made basically a mathematical problem. This will then test the understanding of proportion - figures more difficult.
25	It was felt that the use of state symbols and separate ions recommended in memorandum No.7 (8) had been taken too far by many teachers and that anyway this only serves to make equation balancing even more difficult. The two equations used both involve a 2:1 ratio and the difference in difficulty should lie in the added complexity of state symbols, separate ions etc.
26	To investigate at what level of complexity formulae ceased to meaningfully represent a "shorthand" way of writing the name of a compound (cf memorandum No.7 Page 16.(8).)

Numbers of pupils in each school who completed first questionnaire.

School	Pupil Numbers	No. of Pupils
1	001 - 112	92
2	113 - 213	81
3	216 - 247	32
4	248 - 322	55
5	323 - 435	93
6	436 - 535	80
7	536 - 635	80
	TOTAL	513

Marking Scheme for Test 1.

1. right or wrong. Spelling mistakes ignored.
2. right or wrong.
3. right or wrong.
4. any words, phrase, that carry idea of (a) sharing
   (b) gaining
5. right or wrong. Any reasonable format accepted.
6. Any reasonable format accepted, but proportions and symbols must be correct.
7. right or wrong, spelling mistakes ignored.
8. Any reasonable format accepted, but proportions and symbols must be correct.
9. right or wrong.
10. right or wrong, 'ionic' or 'covalent' format accepted.
11. right or wrong.
12. right or wrong.
13. right or wrong - both symbol and charge must be correct.
14. Any reasonable format accepted, but proportions and symbols must be correct.
15. Symbols accepted - proportion must be correct.

16. right or wrong - symbols and charges must be correct.

17. Any reasonable format accepted but proportions and symbols must be correct.

18. right or wrong.

19. right or wrong.

20. No symbols and no quantatative ideas allowed.

21. Any reasonable description accepted e.g. same formula weights, same number of atoms etc.

22. Used for calculations or equivalent.

23. right or wrong.

24. right or wrong, 6g and $6\frac{2}{3}$g not accepted.

25. right or wrong.

26. No symbols accepted, but only correct names.

In questions 6, 8, 15, 17, 18, pupils often were incorrect because of slips, e.g. wrong symbols, wrong additions, etc. Any pupil who failed because of mistakes like these were marked as having the method correct.

A.2.10.

Ref. No.	Quest. No.	QUESTION ASKED	SCHOOLS							TOTAL	%
			1 92	2 81	3 32	4 55	5 93	6 80	7 80		
1	1	recall of protons, neutrons, electrons (more than one wrong)	0	0	0	0	1	0	0	1	0.0
2	2	recall of electron wrong	9	8	6	4	9	5	9	50	9.7
3	3	had arrangement of $\bar{e}$ in oxygen wrong	24	16	14	6	24	19	36	139	27.1
4	4	did not get idea of oxygen sharing two electrons	37	28	20	11	33	27	40	196	38.2
5	4	did not get idea of oxygen gaining two electrons	39	30	13	9	22	15	23	151	29.4
6	4	had $\bar{e}$ arrangement wrong but idea of sharing $2\bar{e}$ right	11	7	4	3	11	12	16	64	(1) 46.0
7	4	had $\bar{e}$ arrangement wrong but idea of gaining $2\bar{e}$ right	12	9	8	3	13	16	27	88	(1) 63.3
8	4	had both 'gaining' and 'sharing right	25	28	8	35	48	45	29	218	42.5
9	4	had both gaining and sharing right but $\bar{e}$ arrangement wrong	4	3	4	1	6	11	12	51	(1) 36.6
10	4	had neither gaining nor sharing	15	11	9	1	10	8	12	66	12.9
11	5	$\bar{e}$ arrangements - more than 1 wrong	15	18	10	5	20	13	34	115	22.4
12	5	Valence numbers - more than 1 wrong	7	15	21	29	46	27	32	177	34.5
13	5	$\bar{e}$ arrangements wrong, but valence no. right	13	10	2	1	3	1	13	43	(2) 37.3
14	6	binary formulae - 2 or more wrong	26	32	20	48	63	56	50	295	57.5
15	6	binary formulae - method wrong	14	20	12	26	50	35	33	190	37.0
16	6	binary formulae wrong, but method right	12	12	8	22	13	21	17	105	(3) 35.5
17	7	elements in-IDE compound - had 2 or more wrong	16	14	10	21	35	25	33	154	30.0
18	7	included oxygen in IDE compounds	11	12	10	19	18	19	25	114	22.2

Ref. No.	Quest. No.	QUESTION ASKED	SCHOOLS							TOTAL	%
			1 92	2 81	3 32	4 55	5 93	6 80	7 80		
19	8	writing binary formulae from the Periodic Table - 2 or more wrong	30	42	19	50	78	62	61	342	66.6
20	8	writing binary formulae from the Periodic Table - wrong method	21	35	7	35	68	47	31	244	47.5
21	8	writing binary formulae from Periodic Table, method right but got 2 or more wrong	9	7	12	15	10	15	30	98	(3) 28.6
22	8	had elements wrong in Quest. 7 but wrote formulae correctly.	4	1	1	1	0	1	5	13	(4) 8.4
23	8	included oxygen in Quest.7 but wrote formulae correctly	3	1	1	1	0	1	4	11	(5) 9.6
24	8	had elements wrong in Quest. 7 but method for formulae correct	5	1	5	5	2	1	14	33	(4) 21.4
25	8	included oxygen in quest.7 but method for formulae correct	3	1	5	4	1	1	12	27	(5) 23.6
26	9	did NOT get Cl^-	51	59	19	23	43	39	33	267	52.0
27	9	did NOT get idea of gaining $1\bar{e}$	31	37	10	14	25	26	16	159	30.9
28	9	had idea of gaining $1\bar{e}$ but got Cl^- wrong	29	28	10	12	26	19	20	144	(6) 58.5
29	9	had Cl^- right but not idea of gaining 1 electron	10	6	1	3	8	6	4	38	(7) 23.8
30	10	had formula (NaCl)wrong	21	20	9	16	20	12	7	105	20.4
31	10	had NaCl right but had neither idea of gaining $1\bar{e}$ nor Cl^- right	18	20	3	4	9	17	8	79	(8) 65.2
32	10	had NaCl right but Cl^- wrong	39	43	12	13	30	33	27	197	(9) 73.7
33	10	had NaCl right but gaining $1\bar{e}$ wrong	25	23	4	7	15	21	12	107	(7) 67.2
34	11	$\bar{e}$ arrangement of calcium wrong	15	15	12	9	23	10	28	112	21.8
35	12	idea of losing $2\bar{e}$ wrong	16	14	9	8	15	8	24	94	18.3

Ref. No.	Quest. No.	QUESTION ASKED	SCHOOL							TOTAL	%
			1 92	2 81	3 32	4 55	5 93	6 80	7 80		
36	13	Symbol for Calcium ion wrong	65	57	11	18	50	30	22	253	49.3
37	14	formula $CaCl_2$ wrong	21	30	16	17	40	19	16	159	30.9
38	14	$\bar{e}$ arrangement right but losing 2e wrong	3	9	0	3	2	2	7	26	(10) 6.4
39	14	$\bar{e}$ arrangement wrong but losing 2$\bar{e}$ correct	2	10	3	4	10	4	11	43	(11) 38.3
40	14	idea of losing 2$\bar{e}$ right but Ca^{2+} wrong	51	43	5	15	36	25	9	184	(12) 43.9
41	14	losing 2$\bar{e}$ wrong but Ca^{2+} right	2	0	3	5	1	3	11	25	(13) 26.5
42	14	had Ca^{2+} right but $CaCl_2$ wrong	5	7	9	6	7	5	7	46	(14) 17.6
43	14	had Ca^{2+} wrong but $CaCl_2$ right	49	34	4	7	17	16	13	141	(15) 55.7
44	14	losing 2$\bar{e}$ wrong but $CaCl_2$ right	14	6	3	3	3	3	14	46	(16) 48.9
45	14	$\bar{e}$ arrangement wrong but $CaCl_2$ right	13	7	4	4	5	4	19	56	(11) 50.0
46	14	steps 33, 34, 35 wrong but $CaCl_2$ right	10	2	2	0	3	1	4	22	(17) 44.0
47	14	steps 26, 27, 33, 34, 35, wrong but $CaCl_2$ right	4	1	1	0	1	0	1	8	(18) 38.0
48	15	2 or more 'word' formulae wrong	35	37	8	17	45	25	21	188	36.6
49	15	'word' formulae, wrong method used	32	29	2	17	39	21	15	155	(19) 82.4
50	16	3 or more ions wrong	41	55	20	29	66	24	23	258	50.2
51	17	had 1 or more wrong of the first 4 'ionic' formulae	45	70	23	47	84	52	50	371	72.3
52	17	wrong method for 'ionic' formulae	40	43	20	45	76	48	39	311	(20) 83.4
53	17	'ions' correct but formulae wrong	16	17	3	18	19	28	28	129	(21) 50.5
54	17	Ions wrong but formulae correct	11	2	0	0	1	0	1	15	(22) 5.8

Ref. No.	Quest. No.	QUESTION ASKED	SCHOOL							TOTAL	%
			1 92	2 81	3 32	4 55	5 93	6 80	7 80		
55	17	ions wrong but method for formulae right	15	16	3	0	4	1	4	43	(22) 16.6
56	17	formulae for sodium silicate wrong	87	73	27	55	91	79	78	490	95.5
57	17	left out oxygen in Na_2SiO_3	60	37	16	44	73	57	62	349	68.0
58	17	'ionic' formulae wrong but Na_2SiO_3 correct	0	5	1	0	0	0	0	6	(23) 26.0
59	18	2 or more formulae weights wrong	18	29	9	19	37	24	24	160	31.1
60	18	method wrong for formula weights	12	17	6	11	19	19	14	98	19.1
61	19	moles of Fe in Fe_2O_3 wrong	33	75	19	36	72	64	51	350	68.2
62	19	method for formula weights right but moles of Fe wrong	25	59	14	29	55	45	38	265	(24) 63.8
63	20	cannot translate an equation written in formulae	61	42	25	44	83	51	56	362	70.5
64	21	do not understand what is meant by a 'Balanced Equation'	65	50	22	51	73	45	50	356	69.3
65	22	do not know when it is essential to write a balanced equation	82	65	31	35	81	54	48	396	77.1
66	23	had simple 'moles from equation' wrong	64	73	23	43	74	69	65	411	80.1
67	23	had 'harder moles from equation' wrong	85	80	32	52	93	78	79	499	97.2
68	23	simpler moles wrong but harder moles right	3	1	0	0	0	2	0	6	(25) 42.8
69	23	simpler moles right, harder moles wrong	24	8	9	9	19	11	15	95	(26) 93.1
70	24	had proportion calculation wrong	64	56	27	37	76	42	60	362	70.5
71	24	had 'harder moles' in Quest. 23 wrong, but proportion calculation right	24	25	5	15	17	37	20	143	(27) 28.6
72	25	could <u>not</u> balance a 'covalent' equation	47	54	16	50	90	63	56	376	73.2

Ref. No.	Quest. No.	QUESTION ASKED	SCHOOL							TOTAL	%
			1 92	2 81	3 32	4 55	5 93	6 80	7 80		
73	25	could <u>not</u> balance an 'ionic' equation	51	53	18	46	83	52	48	351	68.4
74	25	could balance 'covalent' but not 'ionic'	13	12	5	2	0	8	6	46	8.9
75	25	could balance 'ionic' but not 'covalent'	9	13	3	6	7	19	14	71	13.8
76	26	equation (a) incorrect	18	19	5	17	23	11	7	100	19.4
77	26	equation (b) incorrect	57	56	16	38	57	54	68	346	67.4
78	26	equation (c) incorrect	87	78	29	52	87	74	80	487	94.9
79	26	equation (b) correct, equation (a) incorrect	1	2	0	2	3	1	0	9	(28) 5.3
80	26	equation (c) correct, but equations (a) and (b) incorrect	0	0	0	0	0	0	0	0	(29) 0
81		11 right but 12 wrong	5	7	13	25	29	15	11	105	20.4
82		11 and 12 right but 14 wrong	15	16	2	18	21	31	10	113	22.0
83		11, 12, 13 all correct	57	40	7	7	23	21	24	179	34.8
84		33, 34 right but 35 wrong	49	37	4	14	29	23	6	162	(30) 43.2
85		33, 34, 35 right	25	20	16	29	39	45	39	213	41.5
86		33, 34, 35 right but 36 wrong	5	5	5	4	4	2	3	28	13.1
87		33, 34, 35, 36 right	20	15	11	25	35	43	36	185	36.0

Notes on data pages Appendix 2.10 - 2.14

1. % of those who had $\bar{e}$ arrangement of oxygen wrong.
2. % of those who had $\bar{e}$ arrangement in Quest. 5 wrong.
3. % of those who had 2 or more binary formulae wrong.
4. % of those who had elements wrong in Quest. 7.
5. % of those who included oxygen in Quest. 7.
6. % of those who had idea of gaining 1$\bar{e}$ right in Quest.9.
7. % of those who did not get the idea of gaining 1$\bar{e}$ in Quest. 9.
8. % of those who had neither Cl^- or the idea of 1$\bar{e}$ in Quest.9 (21, 31, 9, 11, 17, 20, 12, = 121)
9. % of those who did not have Cl^- in Question 9.
10. % of those who had $\bar{e}$ arrangement correct in question 11.
11. % of those who had electron arrangement wrong in question 11.
12. % of those who had idea of losing 2$\bar{e}$ correct in question 12.
13. % of those who did NOT have idea of losing 2$\bar{e}$ in question 12.
14. % of those with Ca^{2+} correct.
15. % of those with Ca^{2+} wrong.
16. % of those who had idea of losing 2$\bar{e}$ wrong in question 12.
17. % of those with all steps 33, 34, 35 wrong (12, 5, 6, 3, 12, 3, 9 = 50).
18. % of those with steps 26, 27, 33, 34, 35 wrong (4, 1, 4, 3, 5, 1, 3 = 21).
19. % of those with 2 or more formulae wrong in question 15.
20. % of those with 1 or more formulae wrong in question 17.
21. % of those with ions correct in question 16.
22. % of those with ions wrong in question 16.
23. % of those with Na_2SiO_3 correct.
24. % of those with method for formula weights correct.
25. % of those with 'harder moles' from equation right.
26. % of those with 'simpler moles' correct.
27. % of those with 'harder moles' wrong.

28. % of those with equation (b) correct.

29. % of those with equation (c) correct.

30. % of those with 33 and 34 right.

ATTITUDE QUESTIONNAIRE

This is a questionnaire to discover how you found the various topics that you have studied so far in the third year. Read each carefully and decide how you found it to learn, using one of the four categories, Very Easy (V.E.); Easy (E); Hard (H); Very Hard (V.H.).

	TOPIC	VE	E	H	VH
1.	The structure of the atom - protons, neutrons, electrons.				
2.	Atomic number/mass number.				
3.	Isotopes.				
4.	Mass spectrometer.				
5.	Atomic weights and their determination. Idea of an average value for atomic weights.				
6.	The existance of charged particles - atoms losing and gaining electrons.				
7.	Electrovalent bonds to give ionic solids.				
8.	Electrolysis and conductance by ionic solids, molten or in solution.				
9.	Atoms sharing electrons - covalent bonds.				
10.	Unequal sharing of electrons - polar covalent.				
11.	Writing formulae for simple compounds like water or sodium chloride etc. The use of valence numbers (valency).				
12.	Valence numbers (valency) from an element's position in the Periodic Table.				
13.	Writing (remembering) formulae for complex ions such as 'ammonium'.				
14.	Writing formulae for compounds such as calcium carbonate.				
15.	Putting the charges on formulae e.g. $Ca^{2+}CO_3^{2-}$.				
16.	Calculation of formula weights.				
17.	The 'mole' (gram atom) and calculations using it.				

		VE	E	H	VH
18.	Writing word equations e.g. calcium + water → calcium hydroxide + hydrogen.				
19.	Writing symbol equations e.g. $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$.				
20.	Balancing equations.				
21.	Writing equations with separate ions e.g. $Ca + 2H_2O \rightarrow Ca^{2+} + 2OH^- + H_2$				
22.	Writing equations, putting in all the state symbols e.g. $Ca_{(s)} + 2H_2O_{(l)} \rightarrow Ca^{2+}_{(aq)} + 2(OH^-)_{(aq)} + H_{2(g)}$				

TEACHERS QUESTIONNAIRE

Same as above but with 2 sets of response columns headed:-

How you thought pupils found it to learn	How you found it to teach

A. <u>Pupils Responses</u>

Quest. No.	SCHOOL							Weighted Mean	Standard Deviation	MEAN x 20
	1 (92)	2 (81)	3 (32)	4 (55)	5 (93)	6 (80)	7 (80)			
1	1.772	1.940	1.719	1.709	1.761	1.513	1.913	1.768	0.136	35.4
2	2.022	1.738	2.219	1.873	1.967	1.963	2.165	1.976	0.140	39.5
3	2.529	2.753	2.594	2.673	3.051	2.468	3.205	2.746	0.227	54.9
4	2.333	2.638	2.531	2.782	2.931	3.744	3.063	2.883	0.440	57.7
5	2.615	2.810	2.719	2.764	2.830	2.684	2.775	2.742	0.076	54.9
6	2.533	2.274	2.375	2.400	2.478	2.757	2.513	2.489	0.143	49.8
7	2.750	2.690	2.781	3.091	3.022	2.868	2.900	2.870	0.133	57.4
8	2.511	2.476	2.813	2.636	3.077	2.778	2.704	2.712	0.205	54.2
9	2.163	1.952	2.656	2.673	2.522	2.650	2.475	2.404	0.259	48.1
10	2.337	2.155	3.063	2.727	2.890	3.095	2.688	2.668	0.330	53.4
11	1.793	1.774	2.290	2.418	2.446	1.962	1.463	1.981	0.347	39.6
12	1.598	1.571	2.344	2.691	2.391	2.183	2.150	2.078	0.383	41.6
13	2.185	2.321	3.031	2.855	3.143	2.410	2.288	2.555	0.366	51.1
14	2.098	2.202	2.438	2.455	2.659	2.325	2.163	2.321	0.196	46.4
15	2.878	1.974	2.313	2.691	2.824	2.312	2.125	2.464	0.347	49.3
16	2.250	2.536	2.531	2.655	2.696	2.650	2.188	2.489	0.199	49.8
17	2.761	2.738	3.188	3.127	3.200	3.127	3.088	3.010	0.189	60.2
18	2.424	2.107	2.344	2.400	2.533	2.163	1.988	2.277	0.193	45.5
19	2.581	2.452	2.625	2.855	3.110	2.692	2.550	2.701	0.221	54.0
20	2.913	2.750	2.531	2.455	2.935	2.367	2.913	2.733	0.223	54.7
21	3.187	2.757	3.063	3.000	3.264	2.963	2.925	3.029	0.169	60.6
22	3.191	2.316	2.719	2.745	3.293	3.125	2.913	2.940	0.328	58.8

Total Number of Responses - 513

Question Number	Difficult to teach (mean x 20)	Difficult to learn (mean x 20)
1	36.0	39.6
2	38.0	44.0
3	45.0	54.0
4	47.0	55.3
5	55.0	60.0
6	47.0	55.0
7	49.0	59.0
8	43.0	50.0
9	49.0	55.0
10	53.0	65.0
11	46.0	58.0
12	37.0	45.0
13	48.4	68.4
14	50.0	64.0
15	46.3	63.1
16	40.0	45.0
17	57.0	67.0
18	50.1	49.0
19	55.3	69.4
20	53.6	67.0
21	55.7	67.7
22	55.7	64.2

Total Number of Responses 20

Second Test on Formulae - May, 1971.

U.G./T.H./2

Mark each answer right or wrong.

1. Write the formulae for

   (a) Hydrogen Sulphide

   (b) Phosphorus Oxide

   (c) Boron Fluoride

   (d) Silicon Hydride (pass = 3 or 4 right)

2. Write the formulae for the following ions

   (a) Carbonate

   (b) Sulphate

   (c) Nitrate

   (d) Hydroxide

   (e) Ammonium (pass = 3, 4 or 5 right)

3. Write the formulae for

   (a) Potassium Sulphate

   (b) Magnesium Nitrate

   (c) Ammonium Carbonate

   (d) Iron(III) Hydroxide (pass = 3 or 4 right)

4. Write the formula for

   Sodium Silicate

5. How many moles of oxygen can be produced from heating 1 mole of lead nitrate?

$$2Pb(NO_3)_2 \rightarrow 2PbO + 4NO_2 + O_2$$

Results of Re-Run on formulae etc.

All results shown as % correct response.

School Question	1	2	3	4	5
2	42.3	79.5	52.6	28.2	2.6
3	50.0	81.3	56.3	56.3	18.8
4	4.3	65.7	37.1	8.6	1.4
5	2.1	36.2	33.0	10.6	5.3
7	23.8	92.5	71.3	22.5	26.3
TOTALS	19.2	67.8	48.5	19.2	9.5

Results of 1st Test run on formulae etc.

School Question	1	2	3	4	5
2	48.1	32.1	13.6	9.9	1.2
3	40.6	37.5	34.4	15.6	0.0
4	9.1	47.3	14.5	0.0	5.5
5	16.1	29.0	9.7	2.2	0.0
7	25.0	71.3	37.5	2.5	1.3
TOTALS	27.0	43.4	60.2	5.0	1.5
Schools 1-7	33.0	50.0	27.0	4.0	3.0

Transcripts of Interviews with Pupils

N.B. In this section supplementary questions or other information essential for understanding are shown in brackets.

Ref. number (1)

Main question asked:-

How do you work out the electron arrangement from the atomic number?

Pupil	Replies
1	In the first level there are two, in the next level up there are four boxes, (for oxygen) you fill the bottom two, then in the next row four, there are six, that leaves two half filled.
3	In oxygen there are two in the first, and six in the second.
5	Oxygen's six in the outside level. Its got two in the first level and to make it up to eight, there has got to be six on the outside.
6	The second one (carbon) there are two in the first orbital there can only be two there, in the second one there are four. Four and two if you add them together makes six.
7	You take the number and you have got to add up the electron arrangement - two at the beginning, next step four, so it is two and four, is six electrons.
8	It is two in the first level and four in the next four boxes.
9	Carbon has got six, so it is 2.4 (Why?) Well it has got six electrons and the electrons are arranged in the orbitals and there are two, then the next one is four.

Pupil Replies

10. (for oxygen) Because the sixteen thingmes, I remembered that from the thingme (You remembered there were sixteen electrons) Yes (Why is it 2.8.6) Because there is the inner shell can carry two, then the next one is eight. so there are only six left in the next one. (Is there any way you can work out the arrangement of electrons using the information that is down there?) No.

11. I just got the atomic number, and the electrons were the same.

12. See the atomic mumber is the same as the electron arrangement.

Ref. number (2)

Main question asked:-

How do you work out valence numbers from electron arrangements?

Pupil Replies

1 The number of half filled boxes is the valency number (so for oxygen how do you go from 2.6 to two) it is two, you fill the bottom two, then in the next row four (boxes) there are six, that leaves two half filled and that gives you valency two.

2. It is the number of free orbitals in the last electron ring. The number of empty ones, the number of ones that you could still put something into, to make it up or take it away (How do you work that out) Well in that one (Carbon) it is going to be eight, the maximum you can get into it is eight, and so there are four, the ones you can still get something into.

Pupil	Replies
2.	In this one (oxygen) there are two you can put something into. In that one (fluorine) there is just one you can put something into.
3.	(for carbon) the valency number is four (How do you know it is four) Because there are four half filled orbitals. In oxygen, valency number is two. (Why is it two and not six) Because there are just two half filled orbitals left, two are filled up.
4.	(oxygen) that is 2.6, oxygen is two (why is it two) Because its column, second from the end of the periodic table.
5.	(carbon) four half filled orbitals gives you a valency of four. (oxygen) six on the outside and it has a valency of two because there are only two half filled orbitals.
6.	(carbon) well the first orbital is filled up and the second one has got four instead of a possible eight, therefore there could be another four put on.
7.	You take the last number (from the electron arrangement) you take how many electrons are in the outer orbital. (and is that the combining power, does fluorine have a combining power of seven?) Yes.
8.	Don't know - its the number of half filled boxes (why did you write one for fluorine when there are seven electrons in the outer level) Because there's one half filled box left over. You put them in 1, 2, 3, 4, 5, 6, and 7 and there is one left over.

Pupil Replies

9. From the number of electrons in the outer shell (How do you go then from 2.6 for oxygen to two for the combining power) There are two unused, there are two empty boxes. (for carbon you have written down two - No reply to this and pupil could not work it out.)

10. (so what would it be for carbon?- Carbon has a valency I think it is three (are you just remembering that?) Yes. (Do you know how to work out the combining power from the arrangement of electrons?) No.

11. (Do you know how to go from the arrangement of electrons to valency numbers or combining power?) No.

12. It goes down the way from hydrogen down and then the next column down and when you get to the fifth column it is eight minus law, so eight minus five (But you have not got a periodic table, how do you work it out from what you are given there) Don't know.

Ref. number (3)

Main question asked:-

Explain how you arrive at these formulae.

Pupil Replies

1. Carbon has valency four, hydrogen valency one, so that for every one bond in the hydrogen you need one bond in carbon carbon has four bonds, so you need four hydrogens. (Why did you write CO_2?) It is the short form of C_2O_4. It is the same way as you got CH_4 but only this time oxygen has a valency of two, so for every carbon there is going to be two oxygens.

Pupil	Replies
2.	Hydrogen fluoride that is just HF, CH_4 hydrogen oxide H_2O, carbon oxide is CO_2 (How do you know it is CO_2?) Oxygen has two free ones, which goes over, so that would give that two, the carbon has four, that would come over there, that would make that four. You take that down to the simplest one, that is C_1O_2, but you do not need to bother writing in the one, so you just write CO_2.
3.	(How do you get CH_4) Becasue the valency number of carbon is four and you cross it over, hydrogen is one. (Why did you go from C_2O_4 to CO_2?) Because it cancels by two (What does CO_2 mean?) With every carbon there are two oxygens.
4.	Carbon hydroxide - $C(OH)_4$ (Do you get that?) No. (pupil then changed this to C_1O_2. How do you work out the formula for carbon oxide?) Carbon's valency number is four, oxygen's valency number is two, CO_2 (Why is it CO_2 and not C_2O_4?) Because you swap them over, swap the number over. (If you do that it would be C_2O_4, why have you written C_1O_2?) Because it is two oxygens per carbon.
5.	Carbon symbol C, and hydrogen, hydride, H, carbon has a valency of four, hydrogen one, cross multiply, CH_4 (Explain how you got CO_2 then, rather than C_2O_4) Carbon has a valency of four, oxygen has a valency of two, cross multiply you get two, four, cancel down to one two.
6.	Carbon has four half filled boxes and oxygen has got two and whenever you multiply them round you have carbon with two and oxygen with four, and you cancel them down, carbon can have one and oxygen two.

Pupil	Replies
7.	(pupil wrote CH. Is that right?) No it is CH_4 (How did you arrive at CH_4?) Carbon is in the fourth column of the periodic table, having combining power four and you change combining powers over to the hydrogen to give hydrogen four. (Tell me exactly how you got H_2O) Hydrogen is in the first column, giving it a valency of one, oxygen is in the second column, no it is the sixth column, giving it a valency of two.
8.	(pupil wrote all formulae using atomic numbers as valence numbers. Why did you write six as the combining power for carbon?) OH (Where did the six come from?) Atomic number. (Why have you used atomic numbers for oxygen and carbon and not for fluorine?) Don't know. (Tell me in your own words how you actually write a formula down, give me all the steps.) You put up the atomic numbers at the top or the number of half filled boxes (is the atomic number equal to the number of half filled boxes?) No (What should you have used instead of the atomic number?) The electron arrangements - no - the number of half filled boxes.
9.	Hydrogen and fluorine, combining power one, fluorine is one, so it is one each. Carbon is C, hydroxides OH, hydroxides one, carbons, means that it should be $(OH)_2$. Oxygen is eight, hydrogens H, oxygen is O so, hydrogen one, oxygen two so H_2O. (Explain carefully how you go from the combining power for oxygen and hydrogen to the formula for water of H_2O).

Pupil	Replies
9.	Their combining powers, hydrogen is one, oxygen is two so you reverse them, it is H_2O. (For part 'd' you have gone from a combining power of two for carbon and two for oxygen to be CO_2) It should be one, it should be CO (Why did you write CO_2 the first time?) I hadn't, it would cancel out. (Had you remembered CO_2 from other times or had you just made a mistake?) Just made a mistake.
10.	H for hydrogen, F for fluorine, fluoride and hydrogen is one and fluoride is, I think that is two. (Why is it H_2F?) Because hydrogen is one and I think fluoride is two and you swap them about. Carbon is C, hydrogen is H and that is CH_3 and hydrogen oxide, oxide is O and two H_2O (Why is it H_2O and not HO_2?) Because hydrogen has got one of a valency and oxygen has got two and you just swap them over. Carbon oxide that is C,O, - C_2O_3.
11.	(Pupil could not do this question. Why can you not write the formulae for these questions?) I cannot mind where it is placed on the periodic table - the half filled orbitals. The number of half filled orbitals is its combining power.
12.	The hydrogen H plus fluorine combining power three, hydrogen is one so it is H_3F. (What have you done with the combining power?) flipped them over. Carbon is C cannot do this one, hydride. (Why can't you do it?) Do not know hydride. (You do not know what elements are there) No. Hydrogen plus oxygen, oxygen has got two, hydrogen has got one, flip them over so it is H_2O.

Pupil	Replies
12.	Carbon and oxygen, valency of carbon is three, so it is flipped over $C_2 0_3$.

Ref. number (5)

Main question asked:-

How do you know what elements are present?

(Only pupils 6, 8, 11 (all Class 3) were confused over IDE ending but only 6 actually put oxygen down for each compound. All the rest knew that IDE meant two elements present.)

Pupil	Replies
6.	(You included oxygen into all of them. How do you actually go from the name to what elements are present?) Well -IDE means that there are two and oxygen. (If IDE means that there are two.) Yes, there are two elements and I put oxygen. (Why did you add oxygen?) I thought that is what it would be. (-IDE means what again?) It means that there are two elements present. (And how many elements have you written down?) I put down three for some. (Why?) Well the first one, there is one in there and the second one, I thought had two in it.
8.	You know by - you can tell from the name. (How do you know it contains hydrogen and sulphur and nothing else?) The oxide says there is oxygen there (so what does the ending -IDE tell you?) Don't know.
11.	By looking at the name. The -IDE and you know there should be either two or three elements present. Take the -IDE off and add on the UR for sulphur.

Pupil	Replies
11.	(What does the -IDE tell you?) Oxygen or hydrogen. (Is oxygen present?) Yes. (Pupil did not include oxygen in the answer to the question.)

Ref. number (6)

Main question asked:-

Explain how you work out these formulae using the periodic table.

Pupil	Replies
1.	Get the symbols, it would be H and F, get the valency numbers, cross them over. (Where are you getting the valency numbers from?) The Periodic Table. Boron B, fluorine has a valency of one, boron valency three (How do you know boron is three?) It comes before carbon, it is one less.
2.	The first one is hydrogen H, S is in, the electrons number is leaving us two spare ones at the end to make up the complete shell, so you would manage to get two more to join up with it, so it has a valency of two, put across, so as hydrogen just has the one, so it does not really count, H_2S. Boron fluoride, boron being, it has got a valency of three because you are going to take three out of it to take it to go into the other one (How do you know you are taking three out of it?) It is the easiest way to get it back to an inactive one. (How three?) You are going to take three electrons out. (But why three?) It is because from writing out the arrangement of electrons, it is giving it as three.

Pupil	Replies
2.	(You looked at the periodic table, so how do you know from the periodic table that it is three?) The third column. Phosphorus, that one there is, has three more to fill up. Oxygen just has two and so it is P_2O_3. Silicon is in the same column as carbon so you know that it will have a valency of four and H is in the first one so it is SiH_4.
3.	Hydrogen is in the first column so it has got a combining power of one, sulphur is in the sixth column, it has got a combining power of two, so it is H_2S. (Pupil wrote SiH_3. Why did you give silicon a combining power of three?) It should have been four. (Why?) Because it is in the fourth column.
4.	Hydrogen valency one, sulphur valency number two, so it is H_2S. (How do you know that sulphur has a valency of two?) Because it is under oxygen and oxygen has a valency two, it is in the second column, the columns are in valency numbers, that is 3, 4, 2, 1, 0.
5.	Hydrogen H, sulphur S, hydrogen has one electron, so it has a valency of one, sulphur has two electrons in level so it is H_2S and you cross multiply. (How do you know sulphur has a combining power of two? Were you using the periodic table?) Yes. You work it out to get two electrons, two half filled orbitals in the outer level. (Can you work it out from the Periodic Table?) No reply (You said two, was two mainly from memory?) Mainly, yes

Pupil	Replies
5.	(Try the next one) Boron and fluorine. Boron has a valency of three and fluorine of one, so it is BF_3. (How do you know Boron has a valency of three, you looked at the periodic table?) Yes. It is in the third column so it has got three orbitals in the outer layer.
6.	H represents hydrogen, one half filled orbital, and the S which represents sulphur has got two half filled orbitals. (How did you know that it had two half filled orbitals?) Well in the table it goes from hydrogen one, two and then across to boron three and carbon four and after that it goes three, two, one. You cancel that out and change it round and it goes hydrogen two, sulphur one.
7.	Well the hydrogen sulphide, put down the symbol for hydrogen and then for sulphur. I found what columns they were in the periodic table. I found sulphur to be in the second and the valency to be two. Hydrogen had one so I swapped over the valencies giving hydrogen two and the sulphur one to make H_2S.
8.	You write down H, the letter for hydrogen and S for sulphur and find out the number of half filled boxes for hydrogen one, and for sulphur two. (How do you know that there are two half filled boxes for sulphur from the periodic table?) The first column has got one half filled box, the second column has got two, the third has got three, the fourth has got four, fifth has got three, sixth has got two, seventh has got one, eight has got zero. You write down H and S again, you cross over, you get H_2S.

Pupil	Replies
9.	Hydrogen sulphide, hydrogen is H, sulphide is S, hydrogen has got a combining power of one, sulphur two so reverse them, so it is H_2S. (How do you know sulphur's got a combining power of two? Where did you get it from?) The periodic table. (What is the relationship between position in the periodic table and combining power? How can you look at the periodic table and find out what the combining power is?) The way it is laid out, it is done in metals and non-metals. They are laid out in groups of combining power one, two, three, four. (What about the groups headed with nitrogen?) Nitrogen has got a combining power of three, then three, two, one.
10.	Hydrogen sulphide, S, combining power two, (How do you know the combining power of sulphur is two?) Because you count along the lines to four and then you, ... you count across each row to four and then you count back the way till you come to the last one and its nothing. You have got the phosphorus, the valency that is three, you have got the oxygen, it is two and just turn them round, it is P_2O_3. (And where did you get the combining power of phosphorus and oxygen from, how did you work out what they were?) You count along one, two, three, four and then it goes three, two, one.
11.	H, hydrogen combining power one, S, sulphide combining power two, H_2S, B, boron combining power three, F, fluorine combining power one, B_1F_3.

Pupil Replies

12. The H comes from the hydrogen, sulphide comes from sulphur S, valency of hydrogen is one, valency of sulphur is two flipped over H_2S. (How do you know the valency of sulphur is two, where do you get it from?) The tables. It is the sixth column along, it is eight minus six which is two. (How did you get SiH_4?) Used tables again, looked up silicon and wrote down Si, and looked up hydride as hydrogen and the valency of hydrogen is one and the valency of silicon is four, flip over.

Ref. Number (7)

Main question asked:-

Explain how you fill in the blanks in this equation.

Pupil Replies

1. 2.8.7. (How do you work that out?) Because the seventeen it is two then eight, it is ten of electrons, the next level has the same number of boxes as the one before, there are only seven left. It is going to gain an electron for that one, it is goind to Cl^-, it has got one.

2. (You have written down chlorine gaining one electron to become Cl^+) It is a mistake. (In what way?) Well if it was gaining an electron it would make it negative. (What did you think about when you wrote down positive?) I am not really sure, just a mistake I made in my head. (And how did you work out the arrangement of electrons as being 2.8.7.?) Well I counted that and had eighteen with that at seventeen so I decided to add on another electron.

Pupil	Replies
3.	(How do you know that chlorine becomes Cl^-?) Because there is one extra electron. (Why is it gaining an electron?) Because it is in the last column. It just needs one electron to make its full orbital.
4.	In the example you are given the atomic number so you see that and underneath it you want the shells of electrons, so it will be two for chlorine, 2.8.7. (How do you know it is 2.8.7.?) Because in the first shell there are only two and in the second shell it goes in eights, there are two plus eight plus seven is seventeen. (Why did you write down Cl^-?) Because all the non-metals are negative. Plus one electron (and why is it plus one electron?) because you chlorine itself is neutral so you need to add an electron to make it negative.
5.	To take chlorine to 2.8.8. you need to add on another electron. The first column would be 2.8.7. with seventeen. You have to add on an electron to get it to 2.8.8. (How do you know chlorine is 2.8.7.?) The mass number is seventeen, there are two electrons in the first level, eight in the second and seven in the third. It gains one electron to make 2.8.8. (Why does chlorine become negative?) Because it has gained another electron.
6.	Well chlorine has got seventeen electrons and the formula for that is 2.8.7. and it has got a positive charge and something like a negative charge. The chlorine plus another chlorine would lose, they would gain together and one would lose an electron and it would go onto the other/

Pupil | Replies

6. and the other would lose, one would lose and one would gain and they would be joined together as an atom and that is how they join together. Chlorine is gaining an electron and that makes it up to 2.8.8. its formula, so it has been joined up to another atom, hydrogen because it has got one half filled box. (Pupil wrote $Cl + \underset{2.8.8.}{Cl} \rightarrow Cl$ and changed this to $Cl + H \xrightarrow[2.8.7.]{} Cl$)

7. (How did you know that chlorine was to gain an electron?) Well chlorine in the periodic table was 2.8.7. so it had to gain an electron to become 2.8.8. (Why does it become negatively charged?) Because it has got an extra electron.

8. (How did you know to add one electron?) By working out the levels. (Why have you put Cl^+) Because there is an even number, all the orbitals are filled.

9. Chlorine seventeen, so the arrangement is 2.8.8. and one, it should be 2.8.7. (How do you know it is seven) Well counting out the way electrons are, it should be two is ten and seven is seventeen. This one here has gained an electron. (Pupil wrote + e on the right hand side of the equation and did not fill in the charge for the chloride ion. (What has gained an electron?) This Cl here with it. (Pupil indicated the chloride ion on the right hand side.)

10. I just, it was an e^+ there so I had to take one off the arrangement to make up that (that is 2.8.7.) Yes. (So you have the chlorine gaining what?) Gaining an electron.

Pupil	Replies
10.	(And the charge on the electron?) negative (and you wrote down e^+, why?) Because the electron arrangement there was 2.8.8. and if I had made that a negative, I would have had to go on to another electron cloud. (In fact it is gaining that to make 2.8.8. isn't it?) Yes. (So what ought it to be doing?) no reply. (Why is it Cl^-?) it should be plus because it gained a positive. (Pupil wanted to change Cl^- to Cl^+. If your Cl^- was right?) it would have to be e^- (If you see Cl^- written down, what does it mean has happened to the chlorine?) It has gained a negative. (Pupil did not see mistake and did not want to change his e^+ and left it as $Cl + e^+ \rightarrow Cl^+$)
11.	(Pupil could only attempt the electron arrangement for chlorine and did not know how to attempt the rest of the question even on prompting. How do you work out the electron arrangement?) no reply. (Pupil wrote 2.8.8. and then crossed it out and then could proceed no further.
12.	(Can you tell me how you got 2.8.8. for the arrangement of electrons?) Well it has got seventeen electrons and if you lose one it gets brought down to sixteen and it is 2.8.8, it has got three shells (on the right hand side you are showing that the chlorine is losing one electron) no reply. (Pupil left it as $\underset{2.8.8.}{Cl} \rightarrow \underset{2.8.8.}{Cl + e^-}$)

Ref. Number (8)

Main question asked:-

How do you work out the formula for sodium chloride?

<u>Pupil</u> <u>Replies</u>

1. (How do you know the answer is right by looking at it?) Because the charges balance and cancel each other out.

2. Well I could see from the Li, lithium being in the same one as sodium I could take that as positive and as the chlorine being in the same one as iodine I could take that as a negative, just being above it.

3. Sodium is Na, chlorine is Cl, so it will be Na^+Cl^- (Why one plus and one negative, and why one of each?) Because chlorine just needs one more electron to make it a full orbital.

4. (You have written Na^+Cl^-. How do you know that is right by looking at it?) They are both valency number one, and sodium is a metal so it is positively charged when it is an ion, the chlorine is a non-metal so is negatively charged.

5. (Why is it one sodium to one chlorine?) Because they have each got a valency of one, combining power one. (Can you tell from what you have written down that you have got a combining power of one ?) from the attraction of one positive and one negative.

7. (How do you know it is Na^+Cl^-?) Sodium having gained electrons will become positively charged. Chlorine gained an electron and it is negatively charged.

<u>Pupil</u> <u>Replies</u>

8. The atomic number is eleven, one half filled and the same with chlorine, therefore 1 : 1. (Why have you written $Na^{-}Cl^{-}$?) There is one extra electron so it will be negative.

9. (How do you know by looking at it that the formula is correct? How do you know it is one sodium and one chlorine?) By their combining powers. (How do you know is it Cl^{-} and not Cl^{2-}?) It has only got a valency of one. (If you write down Cl^{-} what does it mean has happened to the chlorine?) Chlorine has lost an electron. (So if you write Cl^{-} it means that chlorine has lost an electron?) Yes.

10. (Pupil wrote NaCl, but added the charges when asked. How did you work the formula out? You used the combining powers from the periodic table?) Yes.

12. Well sodium has got a combining power two, no one plus and chlorine has got a combining power of one negative. (How do you know it is one negative?) Non-metals have a negative charge (and why is it one negative?) Because it has got a valency of one.

Ref. number (9)

Main question asked:-

Explain how you worked out the electron arrangement for calcium?

<u>Pupil</u> <u>Replies</u>

3. There are two electrons in the first orbital so it starts off two, then eight, eight, two.

Pupil	Replies
4.	(Looking at your arrangement of electrons which column of the periodic table would you expect calcium to be in?) The second. (Why?) Because the last one is two.
5.	Calcium is a mass number of twenty, divide up into the electron arrangement, there are two in the first level, eight in the second, eight in the third and two.
6.	You work it out from hydrogen and you work across the table and it works out to 2.8.8.2. If you add up 2.8.8.2. it will come out at twenty.
7.	You have to work it out from the periodic table, how far down it is in the periodic table, then by working out the different levels.
10.	Because calcium has got an atomic number of twenty and in the first one there can only be two, and in the next two there are eight and there are only two left.
11.	There are two in the first level, then eight, then eight and two left.
12.	It has got twenty electrons and it has got three filled shells and only two electrons in the fourth shell.

Ref. number (10)

Main question asked:-

How do you work out how many electrons calcium will lose?

Pupil	Replies
1.	It has got two in the outer shell as it is and if it loses these so that will make it complete.
2.	You try to take it back to eight, being the completely filled one.

Pupil	Replies
4.	The shells in the last one are two, and so you just take away the two and you have got level electron shells.
5.	Because there are two half filled orbitals in the outer level.
6.	Well whenever it has got eight that means that it is usually filled, you cannot add anything to it.
7.	Its electron arrangement is 2.8.8.2. it has to lose two electrons.
8.	There are two half filled boxes, you need to get them to another with two half filled boxes.
9.	Because there are two empty orbitals, two half filled orbitals so it has to to lose them to make it full.
10.	(Pupil wrote 6. Tell me how you worked that out) There can only be eight in the filled shell, no unless it is a special one that has got more than that. (The question asked how many electrons would it lose to have a completely filled level.) I thought it was to gain. (So you put six when you thought it was to gain, to bring it up to eight) Yes. (So what would it be if it lost electrons?) Two.
11.	It has to lose the outside two electrons.
12.	Because it has only got two to lose. It has got a filled shell, it has only got two in an unfilled shell.

Ref. Number (11)

Main question asked:-

Explain how you arrived at your answer for the calcium ion.

Pupil	Replies
1.	Because when it goes to an ion it loses two electrons and this leaves a charge of 2+

Pupil	Replies
2, 3, 5.	Because it has lost two electrons.
4.	Because it is in the second column so it must need two electrons, no, you take away two electrons so it is Ca^{2+}
5.	(Why will it have a double positive charge?) It is losing electrons. (But why a double positive charge?) It was positive before it lost the electrons.
7.	(How do you arrive at Ca^{+}?) Well it starts off Ca^{+} as an ion, that is plus two electrons, it has got to lose the two electrons to make calcium.
8.	(How do you arrive at Ca^{+}?) Because it has an equal number of ions.
9.	(What is an ion?) It is its charge, it is a particle with a charge. (How do you work out the symbol for the calcium ion?) Well, calcium is Ca (What is missing?) The ion charge. (What should it be?) Two negative. (Why is it two negative?) Calcium makes two so it combines two negative (Combining power of two?) Yes. (Why is it two negative?) It has got two half filled orbitals.
10.	(Why have you written Ca_2 down, how did you work that out?) Because the symbol for calcium is Ca and it is in the second column, so I put two after it.
11.	(pupil made no attempt) I don't know how to do that question.
12.	(Pupil wrote 2e, Ca^{2-}) Because it has got a valency of two, calcium, it will have two electrons minus. (It will have two electrons?) It will lose two electrons (What will the symbol for the calcium ion be?)

Pupil	Replies
12.	Ca^{2-}. It is Ca^{2-} because it has lost two electrons.

Ref. number (12)

Main question asked:-

Explain how you arrived at your answer for calcium chloride.

Pupil	Replies
1.	It is, Cl has a valency of one, calcium has a valency of two, so it is going to take two chlorines for every calcium to balance out the charges.
2.	It is for the number of free bonds that you can manage to hook on to. It means that there are two free bonds that chlorines able to go on to and get calcium and so there are two can go to it to make it up to a complete overall equal in charge.
3.	Because chlorine is just one negative charge and it has got to become neutral, so there are two of them. (In order to do what?) Cancel out the Ca^{2+}.
4.	(you have written down $Ca^{2+}Cl_2^{1-}$. How do you actually arrive at this formula?) Because they are all covalent bondings so there is no overall charge.
5.	(Pupil wrote $CaCl_2$ and then added the charges) Calcium is Ca so it has got two electrons, two half filled orbitals, Chlorine is Cl, has only got one, you cross-multiply, you get $CaCl_2$ (You did not worry about balancing the electric charge on the ions, you used a rule, a mechanical method of getting it, for getting the formula?) Yes. (Why have you written Cl^{2-}?) There are two chlorines there already, there should only have been one.

Pupil	Replies
7.	Calcium is positive, the chlorine is negative. (Why two chlorines with the calcium?) Calcium is in the second column in the periodic table, so you change the two from calcium to chlorine.
8.	(Pupil wrote $Ca^{+}Cl_{2}^{-}$) Well calcium 's combining power two, chlorine one (Why Ca^{+} and Cl_{2}^{-}?) Because calcium has got an equal number therefore, positive, chlorine has got an uneven number therefore, it is negative.
9.	(Pupil wrote $Ca_{1}Cl_{2}$ and then added the charges, making Ca^{-}, Cl_{2}^{2+}. What charge do you have on the calcium ion here?) Negative. (and on the chloride?) Positive. (How many?) two positive. (How did you arrive at Ca negative, one negative in this case?) Well, their combining power, the formula is $Ca_{1}Cl_{2}$. (How did the chlorine arrive at a double positive charge? What had to happen to it to arrive at a double positive charge?) Well it gained two electrons.
10.	(Pupil wrote $CaCl_{2}$ and then added the charges $Ca^{-}Cl_{2}^{+}$. Tell me how you actually worked out the charges on that compound?) Because calcium had lost its two valency power to chlorine and that would be negative, then chlorine gained them so that is positive. (How many did the calcium lose?) Two. (So you have written down Ca^{-} and Cl_{2}^{+}) Yes. (Pupil did not wish to change these charges.)
11.	(Pupil wrote $Ca^{II}Cl^{I}$, then $Ca_{1}Cl_{2}$ and then added charges making $Ca^{+}Cl_{2}^{-}$) I wrote down the valence numbers and crossed them over. (How did you work out the charges on the ions?) I don't know.

Pupil Replies

12. (Pupil wrote $Ca^{2-}Cl^{2-}$) You flip over the electrons. First take the calcium to chlorine and calcium to chlorine two of each so it will be zero. (So if it is two of each you keep the charge zero?) Yes.

Ref. Number (14)

Main question asked:-

How do you arrive at the formulae for these ions.

Pupil Replies

All the pupils except Number 10, stated that they just had to memorise these ions. None of them knew any way of checking on the accuracy of their memory.

5. (Do you have any way of checking to see if they are right?) Well, there should be.

10. (Pupil wrote C_2^+; S_2^-; H^+; N_3^-; NH_4^+; How did you work out the formulae for these ions?) The ones after the fourth column were the negative ones, the ones before it were the positive ones. (How do you arrive at carbonate as C_2^+?) Because carbon was in the second column and it was a plus. (How do you arrive at nitrate as N_3^-?) Well nitrate was in the, after the fourth column, in the fifth one and that was three and it was negative. (Does the -ATE at the end of a name tell you anything?) It has two things in it, two compounds that should have been NO, nitrate should have been NO.

Ref. Number (16)

Main question asked:-

Explain how you worked out these formulae.

Pupil	Replies
1.	K is the symbol for potassium and it has got a valency of one, it will be 1+ because it is going to lose an electron. (This (sulphate) has got two minus, it is going to take two of the K for every one of the sulphate ion. (Why do you put brackets around the OH in iron hydroxide?) Because it is three of the complete ions, not three hydrogens.
3.	(Why have you written $(NH_4)_2$, carbonate thus giving the carbonate ion a combining power of two when in the previous question you gave it a combining power of one - Pupil had written (CO_3^-)) It should have a combining power of two. (So you remembered it was two?) Yes. (Did that come from habit, from writing formulae down? Have you written $(NH_4)_2CO_3$ sufficiently often for it to stick in your mind as right?) No. (What convinces you that two is right?) I can remember it written down in the table above sulphate. (Why did you put the brackets around the OH?) Because it is the whole lot two times.
4.	Potassium is **K**, sulphate is SO_4, there is nothing else. (Pupil used (SO_4^-)) Magnesium is Mg, nitrate is NO_3 (Pupil used NO_3^-). Why do you put twice after the ammonium?) Because carbonate is valency number one. (Pupil had written CO_3^- in previous question) and ammonium is valency number, you swap the numbers over.

Pupil	Replies
5.	Potassium K, sulphates SO_4, potassium has a valency of one, sulphate has a valency of two, cross multiply K_2SO_4.
7.	(Pupil wrote Mg_1 $(NO_3)_1$. When you wrote magnesium nitrate, what combining power have you given to the nitrate?) No combining power. (None?) Yes. (How did you work out Mg_1 $(NO_3)_1$?) No reply. (Tell me first how you wrote potassium sulphate) I found the symbol for potassium to be K, and sulphate SO_4, sulphate has got a combining power of two, potassium has got a combining power of one. (Pupil wrote K_2SO_4) Magnesium has a combining power of two, the nitrate has got a combining power of one, so nitrate will be given a combining power of two. (Why did you put the brackets around the OH?) If you did not put the brackets in, you would be tripling the hydrogen and not the oxygen.
9.	Potassium is K, combining power of one, sulphate SO_4, combining power of two, change across, it is K_2SO_4. Ammonium is NH_4, combining power of one, carbonate CO_3, change across $(NH_4)_2CO_3$. Iron Fe, combining power of three, hydroxide H, combining power of one so it is $Fe_1(OH)_3$. (Why do you put the brackets around the OH?) Well you know you are not going to mix them up with the combining power. (Would it have been all right to write $Fe(OH)_3$ without the brackets?) Yes it would.

Pupil	Replies
10.	Potassium K and sulphate is SO_4. (Pupil wrote $K^1(SO_4)^2$ and made this $K_2(SO_4)$. So (SO_4) has a valency, combining power of two. How do you know the formula is SO_4 and combining power two?) Just remembered that, Magnesium is Mg, nitrate is NO, NO twice. (Why is it NO twice?) Because magnesium has got a valency of two. (and what is the valency of NO then?) One. Ammonium is NH_4 and carbonate is CO and just put the four off the NH. (Pupil wrote $NH(CO)_4$) it should be NH_4, that should be CO. (Pupil wrote $NH_4(CO)$.
12.	Potassium is K, sulphate is SO_4, potassium has got a charge of one and that got two electrons (Pupil wrote K^-SO_4. If you do have to put the charges on potassium sulphate, how do you do it?) Flip over the sulphates charges and the potassium's charges. Potassium has got one negative, sulphate has got two electrons, flip over, it's potassium would have two electrons, and sulphate would have one electron. (Pupil wrote $K^{2e}SO_4^{-1}$). Magnesium Mg, nitrate NO_3, magnesium has got a valency of two and nitrate has got a valency of two, it will be just the same ($MgNO_3$) Ammonium is NH_4, plus carbonate CO_3, both got a valency of two, it will be just the same (NH_4CO_3) Fe, three, hydroxides OH, iron has got a valency of three and hydroxide has got a valency of two, flip them over, it is $Fe_2(OH)_3$. (Pupil used NO_3^{2-}; NH_4^{2-}; CO_3^{2-}; OH^{2-} in the previous question. Do you need a bracket around the OH?) Yes, so it is not just OH three, three hydrogen.

Ref. Number (18)

Main question asked:-

Explain how you arrived at the formula for sodium silicate.

Pupil	Replies
1.	Silicon is in the same column as carbon, it is going to make the same ion with oxygen, with the same valency.
2.	Silicon is in the same column as carbon so you take silicate as carbonate.
3.	It is in the same column as carbon, silicon, so it will have the same valency, combining power. (Why SiO_3?) Because it has the same combining power as carbon. (And will be like?) Carbonate.
4.	Silicate, plus oxygen, that is SiO, silicon is underneath carbon so that is silicate, maybe I missed out something, SiO_3, it is the same as using carbon and I think it has got a valency number of two.
5.	Silicon is in the same column as carbon, you just use the carbonate and replace the carbon with silicon.
7.	Silicon is in the same column as carbon, it must be given the same combining power carbonate has, so I gave it SiO_3, a combining power of twice.
9.	Well carbonate is CO_3 combining power of two, so, silicate is in the same group, so it must be SiO_3.
10.	I do not know that one. (Have you any way of working it out?) Just getting the formula from the silicon and the oxygen and putting it together. (Do you know how you could work it out?) No. Haven't had that before.

Pupil	Replies
12.	I do not know that one. (How do you work it out?) Si, silicate, means there are two elements, sodium has got a valency of one and silicon has got a valency of two, flip over, it is Na_4Si. (So silicon has got a valency of four?) No reply.

Calculation of correlation coefficients

Each item in the questionnaire was given 3 scores viz.

(1) an average assessment of difficulty by pupils

(2) an average assessment of "learning" difficulty by teachers

(3) an average assessment of "teaching" difficulty by teachers.

Similarly actual performance in Test 1 and the re-run was taken as the average pupil performance in a question.

Pearson correlation coefficients were worked out using the formula given on page 2.18 using these average 'scores' on a question basis i.e. average score group x on question 1 compared with average score group y on question 1 and so on for question 2, 3, etc.

r_1 pupil response v teachers "to teach".

r_2 Pupil response v teachers "pupils to learn"

r_3 teachers "to teach" v teachers "pupils to learn".

r_4 pupils response v performance in test 1.

r_5 teachers "to learn" v performance in test 1.

r_6 test 1 score v re-run score (Schools 2, 3, 4, 5, 7)

r_7 test 1 score v test 1 score

(Schools 2,3,4,5,7,) (Schools 1-7)

Principles Behind Construction of Gagné Net

The net was based on the ideas outlined by Robert Gagné(14) and was constructed to show three distinct routes by which pupils might arrive at formulae

(1) A mechanical approach using rote learning rules and a minimum of understanding i.e. functioning at the Knowledge and Comprehension level.

(2) An ionic approach using a certain amount of learned rules but showing all the steps necessary for understanding so that a pupil may function at the Application level.

(3) A covalent approach being as above but omitting the steps involving ion formation.

Calculation of Degree of Difficulty

It is appreciated that the method of matching subjective degrees of difficulty, an ordinal scale, to a set of cardinal numbers is open to criticism, but it does give a qualitative picture of the level of difficulty involved in a question. No attempt has been made to say that a question difficulty level 4 is four times as hard as one with difficulty level 1.

CHAPTER 3

PRE-EXPERIMENTAL PLANNING AND DESIGN OF THE REVISED TEACHING ORDER.

Introduction

With the evidence provided by the 1st test and questionnaire showing that a large proportion of formulae and equations seemed to be memorised, it was time to re-examine the teaching order in SIII and SIV in order to spread the memory load over a period of time.

This gradual revelation of formulae and equations would have two main advantages.

(1) The pupils would learn a little at a time, practising what they had learnt and seeing its relevance.

(2) Pupils would not be overwhelmed by a flood of difficulties during the concentrated work on formulae at the start of the third year.

The maturity study carried out by A. H. Johnstone(1) at Glasgow had shown that

(1) work carried out in Class 4 was done better than that done in Class 3.

(2) pupils could competently handle the "organic" work in Class 3.

In this study however, all pupils had completed the work on formulae and equations in one block before setting out on different routes. Pupils who followed the "organic" route made no real use of their hard learned formulae of compounds, such as sodium sulphate, for nearly a year. The author felt that in any further study formulae and equations must be revealed slowly so that pupils learnt, and used, only a level of complexity that was essential to the problem in hand. To achieve this aim a new syllabus order had to be devised.

Construction of the New Teaching Order

In the construction of the revised teaching order, the following guidelines were thought to be important.

(1) As the "organic" side of the syllabus had been successfully taught in Class 3 and as the 'ionic' work was better left to Class 4 (1) then the syllabus order should be basically "organic" first.

(2) Formulae and equations were to be introduced gradually during Class 3.

(3) The mole concept and proportion calculations were to be left until Class 4 if possible.

(4) Pupils were to have sufficient areas of work left to practice adequately their newly learnt skills of formula writing, calculations etc.

(5) There should be a relatively easy part of the syllabus left to be completed in the final stages of the run up to the '0' grade examination to allow concentration and practice on revision topics.

(6) The amount and complexity of equation writing was to be kept to a minimum.

The first step taken was to examine the S.C.E.E.B. '0' grade syllabus (2) and establish what level of formulae and equation writing was the MINIMUM required for any particular section.

This examination is given in detail in Appendix page A.3.01 - A.3.04 the following being a summary.

Full ionic/covalent formulae	Simple i.e. binary	"organic" i.e. structural	words
H(5) - (9) J(5) - (8)	H(2), (4) I(5) K(6) M(2)	L N O	rest

There are of course very valid objections to using the absolute minimum complexity. They are:-

(1) writing full names of compounds in both formulae and equations can be very tedious and time consuming.

(2) pupils would not have written enough symbol formulae or equations to give them adequate facility (or indeed a chance for them to be imprinted) for their use when they are essential e.g. in calculations.

(3) Although pupils may be able to understand the meaning behind for example the redox pair

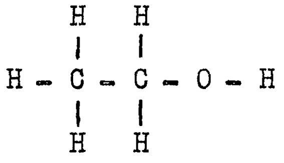
$$Zn \longrightarrow Zn^{2+} + 2\bar{e}$$

$$2\bar{e} + Cu^{2+} \longrightarrow Cu$$

if this is the only form of equation they meet then they can find it difficult to relate this to the real life situation of a piece of Zinc dropping into copper sulphate solution.

Consequently simple binary formulae should be introduced as soon as possible along with the related organic structural formulae. In the experience of teachers in school 1 pupils found these relatively easy when approached from the "carbon must always have 4 bonds" standpoint and when formulae are written e.g.

(i)



$$H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-O-H$$

or (ii) CH_3CH_2OH

and <u>never</u> as (iii) C_2H_5OH. The expanded form, as in (i), is to be preferred with progression to (ii) only when understanding is sufficient. Use of type (iii) should be reserved until very much later, if indeed used at all.

When pupils use extended structural formulae for organic compounds this is a concrete operation, a physical act of writing each atom and all the necessary bonds. They do not have to conceptualise to try and reconcile formulae such as Na_2SiO_3 or C_2H_5OH with the real world of molecules and ionic lattices.

Having established the level of formulae to be used, the new syllabus order was devised. This is given in appendix A.3.05-A.3.08. along with any relevant explanations.

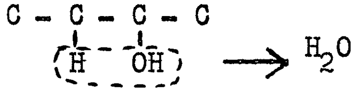
Details of Syllabus Order Construction

N.B. (i) NIL word formulae only e.g. sodium chloride

(ii) $\frac{1}{2}$ equations involving oxyanions are provided in the data book used in the S.C.E.E.B. examinations (19) and therefore need only be copied.

Section	Topic	Level of Formulae required
G1	Evidence for atomic nature of matter	NIL, symbols only.
G2	Symbols for elements.	" " "
G3	Constituents of atoms and their arrangement in the atom	" " "
G4	Atomic number	" " "
G5	Mass numbers	" " "
G6	Isotopes	" " "
G7	Atomic Weights	" " "
H1	Conduction of electricity by substances.	NIL
H2	Model of chemical combination which fits in with the facts discovered in H1.	Simple formulae e.g. Na^+Cl^- based on use of atomic structure and the fact that the overall charge in a compound is zero.
H3	Experiments to support the ionic theory.	NIL
H4	Conductivity related to number and mobility of ions.	This is best left to much later in the order but requires HCl, NaOH and NaCl.
H5)	Chemical formulae	Full formula knowledge required and the ability to deal with percentage compositions.
H6)	Ions containing more than one element.	
H7)	Deduction of chemical formulae from analysis.	
H8)	Formula weights.	
H9	Equations and their use in chemical calculations.	Full use of formulae and balanced equations.
I1	Action of metals on oxygen water and acids.	By considering only the relevant species involved, then equations such as $Na \rightarrow Na^+ + \bar{e}$; $2Cl^- \rightarrow Cl_2 + 2\bar{e}$ are sufficient.
I2	Displacement of one metal by another	as for (1)

Section	Topic	Level of Formulae required
I3	Reduction of oxides	Formulae for binary compounds but unless a calculation was involved, words could be used.
I4	Do all metals form ions equally readily in solution	NIL
I5	The ionisation of water.	Formula for water.
I6	Oxidation and Reduction as transfer of electrons. Electrolytic oxidation and reduction.	NIL if similar equations are used as in I1 and I2.
I7	Corrosion of metals and protection.	as for 6.
J1	Acidic and basic oxides	NIL.
J2	The Hydrogen ion $H^+_{(aq)}$.	NIL
J3	Characteristics of acids.	NIL if word equations or equations involving only relevant species are used.
J4	pH and its uses	NIL.
J5)	The OH^- ion and the characteristics of bases.	If acids are treated as sources of H^+, alkalis as sources of OH^- all volumetric calculations can be achieved by (i) writing correct formulae (ii) making the No. of H^+ = No. of OH^- e.g. (a) $NaOH \rightarrow 1 \times OH^-$ (b) $H_2SO_4 \rightarrow 2 \times H^+$ then $2 \times (a) \equiv 1 \times (b)$. No equations need be written therefore except $H^+ + OH^- \rightarrow H_2O$
J8)	Simple volumetric work involving acids and bases.	
J6	The process of Neutralisation and precipitation Heat of neutralisation.	If the right solutions are chosen then only word equations and names of compounds are essential.
J7	Preparation of salts.	NIL.
J9	Preferential discharge of ions (a) electrolysis of dilute sulphuric acid (b) electrolysis of sodium halide solutions.	NIL - when equations involving only relevant species are used.
K1	'Burning' of ion pyrites and sulphur in air as industrial sources of sulphur dioxide	NIL.
K2	Properties of sulphur dioxide	NIL

Section	Topic	Level of Formulae required
K3	SO_3^{2-} as an electron donor	NIL - ionic equations involving oxyanions are not required at '0' grade, therefore word equations will suffice.
K4	Conversion of sulphur dioxide into sulphur trioxide.	NIL
K5	Conversion of sulphir trioxide into sulphuric acid	NIL
K6	Properties of concentrated and dilute sulphuric acid	formula for water e.g.  $C - \underset{H}{C} - \underset{OH}{C} - C \longrightarrow H_2O$
K7	Industrial uses of sulphuric acid.	NIL.
L1	The element carbon - different forms	NIL.
L2	Combustion of carbon	NIL.
L3	Saturated Hydrocarbons	"Organic" covalent type formulae based on Carbon forming 4 bonds, oxygen 2 bonds, hydrogen 1 bond. As structure is of importance here and naming by words would often be very tedious, this type of formula is essential.
L4	Oil and natural gas	As for 3
L5	Hydrocarbons as fuels	As for 3.
L6	Unsaturated hydrocarbons	As for 3.N.B. it is important here for pupils to know the difference in structure between C_2H_4 and C_2H_6 and to appreciate on a simple level the reason for Bromine addition to C_2H_4.
M1	Nitrogen	NIL
M2	Ammonia	NIL
M3	Manufacture of ammonia by Haber synthesis.	NIL
M4	Oxidation of ammonia	NIL.
M5	Properties of Nitric Acid (a) as an acid (b) as an electron acceptor	NIL if equations involving only relevant species are used (ionic equations with oxyanions not needed at '0' grade.)

Section	Topic	Level of Formulae required
M6	Nitrogenous fertilizers	NIL
M7	Nitrogen cycle	NIL
N1	Carbohydrates	No structural formulae required in excess of the simple polymer model - use names.
N2	Alcohols, acids, esters	Words could be used here but this might make the idea of esterification even more difficult when pupils could not picture or visualise the loss of H and OH. The use of formula as used in L3 can be continued, e.g. seeing ethanol as based on ethane.
N3	Fats and detergents	Exact formulae are not important here. Use words and simple diagrams.
N4	Proteins	Treat as for carbohydrates. Need for functional group structure for amino acids.
O1	Synthetic polymers	Formulae as in L3 and N1.
O2	Silicones	Formulae as in L3 and N1.

A.3.05

Revised Teaching Order

Approx. Time Scale	Ref. No.	Topic	S.C.E.E.B. Section Number
Aug.	1	Atomic structure etc.	G1 - G7
	2	Simple ideas on bonding (ionic, covalent, metallic)	H1 - H3
	3	Simple binary formulae (from the periodic table). Do <u>not</u> insist on charges on the ions. NaCl is acceptable.	H5
Oct. Jan.	4	Fuels and related substances (exclude addition polymers). Always use structural formulae (to show carbon valency 4 etc.) and equations (which need not be balanced) treated as a summary of what has happened.	L1 - L6
	5	Foodstuffs and related substances (i) Carbohydrates, alcohols, acids, esters. Quick revision of the idea of ions and how they arise - do not include complex structure e.g. SO_4^{2-}	N1 - N2
		(ii) fats and detergents	N3
March		(iii) Proteins N.B. leave the explanation of basic character of the amines till M2	N4
April	6	Formulae of oxyanions such as sulphate and compounds containing these.	H6
May	7	Simple equations - include those of the type $Fe \longrightarrow Fe^{2+} + 2\bar{e}$	[illegible]
	8	Reactivity series, corrosion. Write equations in terms of relevant species.	I1 - I7
June	9	The mole concept, formula weights etc.	H7 - H8
	10	Balancing equations and their use	H9
	11	Sulphur Chemistry	K1 - K7
Aug.	11	Sulphur Chemistry	K1 - K7
Oct.	12	Nitrogen Chemistry. Use these sections (K and M) as good practice for balancing equations and their use for calculations.	M1 - M7
	13	pH, conductivity etc. (Include section H4 here)	J1 - J6 H4
Jan.	14	Simple volumetric work. Bring in the concept of MOLAR solutions, and simple calculations on molarities.	J8
	15	Preparations of salts - interconversions (good practice at writing equations.)	J7
	16	Preferential discharge of ions, electrolysis.	J9
Mid Feb.	17	Macromolecules	01 - 02

Comments.

Ref.

2,5 By introducing bonding and therefore the idea of the existence of ions at Stage 2, the teacher is able to use Stage 5 as a time for reinforcement, checking and revision of this difficult area.

3 Introducing binary formulae at this stage will give formulae of sufficient complexity to deal with stages 4, 5, but are to be used to convey which atoms are present, and how many of each. Hence 'covalent' formulae are sufficient.

5(ii) Even though most schools probably follow carbohydrates with a study of proteins as in Chemistry Takes Shape(25), it was felt that, as in the S.C.E.E.B. scheme, fats and detergents followed more naturally the study of esters.

5(iii) As the pupils have not met the concepts of acids and alkalis, the explanation of basic character must be left until Stage 12.

6 The ions that are introduced here should be only those that the pupil is going to use commonly, namely:-

Hydroxide $(OH)^-$ Sulphate $(SO_4)^{2-}$ Phosphate $(PO_4)^{3-}$
Nitrate $(NO_3)^-$ Carbonate $(CO_3)^{2-}$
Ammonium $(NH_4)^+$

The need to include Phosphate is very debatable at this stage and can be profitably omitted.

The extrapolation of e.g. Carbonate to Silicate is a process well beyond most pupils at this stage, and should be left until a lot later.

Formulae should be written covalently e.g. H_2SO_4.

Ref.

7,8 Reactivity series and corrosion provide good practice material for writing simple equations, hence formulae amd equations of the type $Fe \longrightarrow Fe^{2+} + 2\bar{e}$ remove the need for formulae written ionically e.g. $Cu^{2+} + SO_4^{2-}$

9,10 The mole concept is introduced here, towards the end of Class 3, to enable teachers to start Class 4 with a revision of the topic. Thus this difficult concept is introduced, given a little practice in June of Class 3, allowed to ferment over the summer break, revitalised in August and then put to work in the Chemistry of Sulphur and Nitrogen.

11,12 These sections are essential practice for balancing equations and calculations.

13 Formulae of the type $2Na^+ + SO_4^{2-}$ must be introduced and used. The state symbol (aq) can be introduced but it is doubtful how much information it transmits to the pupil.

14 Having given the mole concept time to be assimilated, progression can now be made to the concept of a MOLAR solution.

15 This very practical stage is less intellectually demanding than many and allows the teacher to revise past work while giving essential practice at writing equations.

16 Putting section J9 here allows the teacher to revise

(a) Ion formation

(b) oxidation/reduction

(c) simple equation writing

(d) reactivity series

(e) mole concept

17 This relatively straightforward and practical stage which is not conceptually demanding gives pupils

(a) a pleasant end to their '0' grade course,

(b) time for more revision.

CHAPTER 4

PHASE 2 - MATURITY STUDY INVOLVING THE REVISED TEACHING ORDER AND ATTITUDE QUESTIONNAIRE.

Experimental Design

1. Set up a teaching situation in order to evaluate the revised teaching order, having both experimental and control groups. This would involve the two year period from the start of Class 3 to the 'O' grade examination at the end of Class 4.

2. Devise a number of tests to measure pupil performance in the areas of formulae, equations and the mole.

3. Gather from schools 'O' grade results in Chemistry and relevant I.Q. data where possible.

4. Statistically compare the performance of the groups involved.

5. Draw valid conclusions.

6. Carry out a similar attitude survey as in Phase 1, at the end of Class 4.

7. Draw valid conclusions.

Selection of schools

About 20 schools were selected to give a reasonable cross-section of pupils. The Heads of their Chemistry departments were met personally and the revised order explained. Some had to decline for administrative reasons, others accepted to be purely controls. The list of schools who accepted is given in Appendix page A.4.01. The final roll of schools still gave a sample which contained schools from a wide variety of situations, reflecting the whole Scottish situation. Internal difficulties in schools led to there being three teaching orders, see diagram 4.01 on page 4.011. It was hoped that schools would be able to provide 'matched' groups of pupils i.e. that pupils would be divided into two groups on the basis of performance in Class 2, so that the two groups were equal in ability and performance. Each group could then be subdivided into teaching sets. It was not possible to obtain this ideal and the resultant arrangement is shown in the table on Page 4.02.

A general outline of the three teaching orders.

REVISED	STANDARD I	STANDARD II
Atomic Theory	Atomic Theory	Atomic Theory
Binary Formulae	Binary Formulae	Binary Formulae
Organic	Oxyanion Formulae	Oxyanion Formulae
Oxyanion Formulae	Equations/Mole	Equations/Mole
Reactivity	Organic	Reactivity
Equations/Mole	Reactivity	Conductivity
Sulphur & Nitrogen	Conductivity	Sulphur & Nitrogen
Conductivity	Sulphur & Nitrogen	Organic

Diagram 4.01.

School Number(s)	Description of situation
4,5	All pupils following the traditional order - to be called Standard (II)
1, 3, 7, 14	All pupils following the Revised order.
9, 10, 12, 15	Pupils divided into 2 approximately matched groups (a) following Standard II order (b) following Revised order.
2, 8, 13, 16	Pupils divided into 2 approximately matched groups (a) following 'organic first' order but with all formulae, equations and calculations at the start - to be called Standard (I) (b) following Revised order.
11	All pupils following Standard (I) order.

This arrangement meant that a number of different aspects could be examined at the one time.

(1) Does the revised route make the course significantly easier for pupils?

(2) Does having the school only partly committed to the revised order i.e. with matched groups, affect significantly the performance of either group with respect to schools wholly committed one way or the other?

(3) Does the gradual revelation of equations have a significant advantage over 'en bloc' revelation when pupils follow the organic first teaching order?

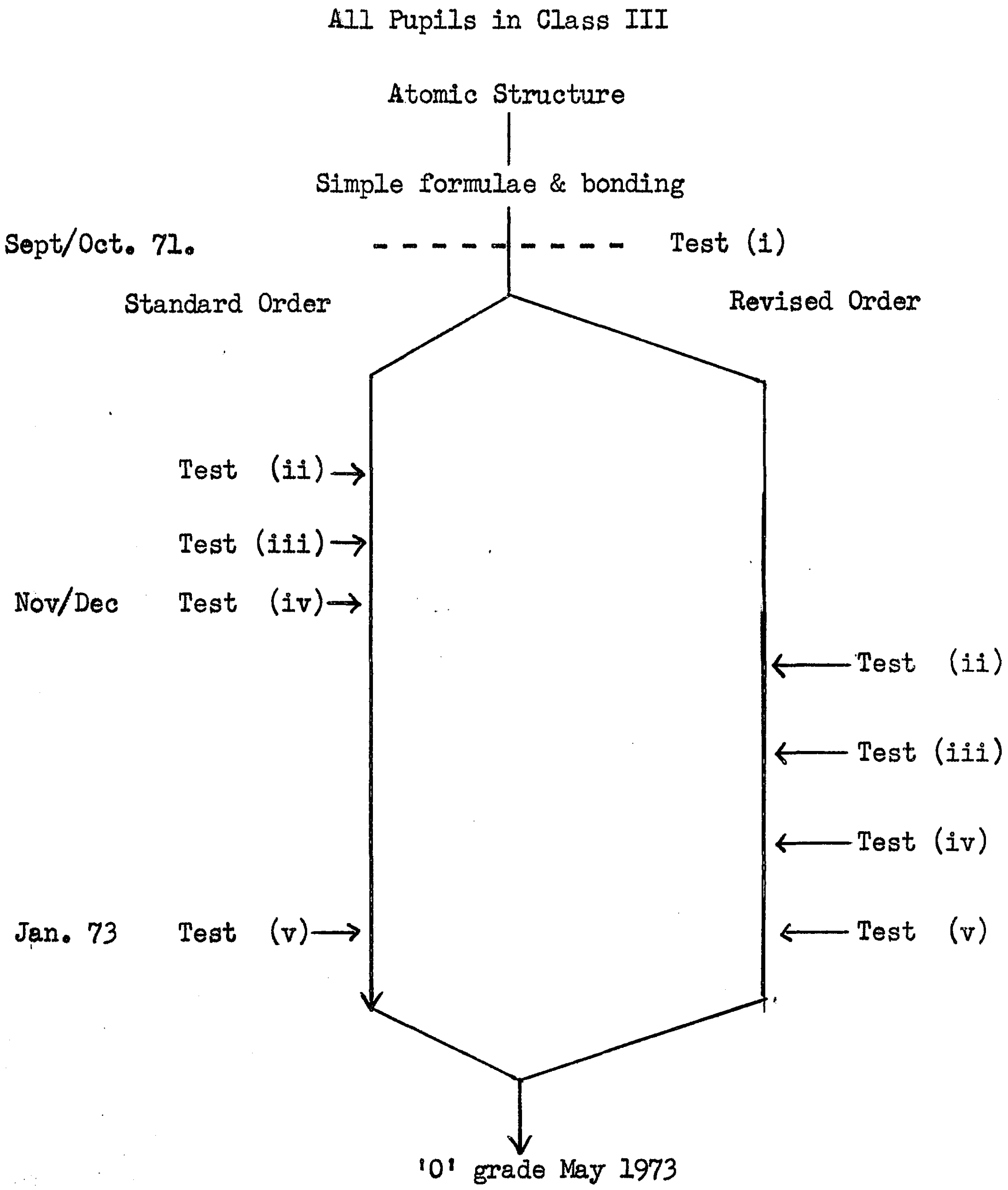
Testing Procedures

(a) It was decided to administer 5 short 20 mark tests, one for each topic, as given below:-

(i) Binary formulae
(ii) Formulae with oxyanions
(iii) Formula weights and the mole
(iv) Balancing equations and calculations
(v) Revision of (i) - (iv)

The final comparisons would be taken from the results of the May 1973 '0' grade examination.

(b) Pupils would sit the tests whenever they had completed the relevant work, with test 5 being at a common time. The approximate timetable is shown below:-



Test Construction

It was decided to make these tests of either fixed response questions or where appropriate, questions involving only one or two word answers to make marking as objective as possible.

A complete fixed response layout was rejected in order to allow for testing of understanding rather than recognition in various parts of the test, even though this made analysis of the results more difficult.

The completed tests are given in appendix page A.4.02–A4.17 along with the reasoning steps involved.

Teachers marked the tests according to fixed marking schemes details of which are given in Appendix page A.4.18–A.4.22 and sent in their results on a mark return sheet (see appendix page A.4.23) and on receipt of this were sent copies of the next test. Although returning marks in this format forbade any detailed investigation into performance on specific questions, it was felt that as so much of the success depended upon teachers good will, then they ought not to be asked to provide a detailed analysis which would be time consuming. However, for Test 5 it was felt that a special effort would provide useful information, and a detailed mark return sheet was sent out with this test. A copy is given in appendix page A.4.24.

Administration

Schools were asked to teach pupils

(a) as they had traditionally – Standard II.

OR (b) formulae, equations "en bloc" followed by the organic first – Standard I (This corresponds to the covalent group of A. H. Johnstone(1)).

OR (c) according to the Revised scheme and using the approach to formulae and equations suggested during the visit.

Schools that were providing 'matched groups' did so on the basis of performance in Class 2 in Chemistry or Science. The experiment was launched in August 1971 and the pupils of Class 3 followed through to the '0' grade examinations in May 1973. After the experiment had been concluded, I.Q. data were requested from schools to see whether the ability levels in the various groups of schools were reasonably similar. (See Appendix page A.4.25)

Results

The results are tabulated in Appendix page A.4.26-A.4.28. Some schools, for various reasons, did not send in the results of some tests. These are shown as blanks in the tables.

Calculations.

Means and standard deviations were calculated using scores of 2, 7, 12, 18 for the bands 0 - 4, 5 - 9, 10 - 14, $\geqslant$ 15 respectively.

Because many schools did not wish to split their pupils into 2 different teaching orders, but were prepared to enter into the research on the basis of all one way or the other, it was not possible to obtain completely, schools with matched groups. It was hoped that it would be possible to match schools from the different orders to give comparable samples, but this proved extremely difficult.

Formulae, equations and calculations form only a part of the S.C.E. '0' grade examination but this examination can be taken as the best available assessment of the overall chemical ability of the pupils. Product moment correlations (as on page A2.52) were calculated between the results of Test 1 and '0' grade scores for the various teaching orders. These were quite high.

	Revised	Standard (I)	Standard (II)
τ (test 1 v '0')	0.6	0.7	0.6 **

** School 4 omitted because its results from Tests 1 & 2 were anomalous caused by internal difficulties.

Bearing in mind also that any differences in teaching up to Test 1 should be minimal between the groups, it was decided to use Test 1 as a pre-test in order to balance the 3 teaching groups.

It was obvious that the schools which were following the revised order entirely could not be matched directly with those following the Standard II order - there being too large a disparity in means on Test 1. Even within those schools whose groups had been matched on the basis of second year performance there was a considerable variation. To overcome this the following procedure was adopted.

Schools were picked from the 3 teaching groups to give samples that had

(1) means, as shown in the total columns page 4.061 - 4.063, differing by less than ¼ standard deviation,

(2) comparable total numbers,

(3) comparable standard deviations;

for each of the comparisons that were to be made.

Deatils of schools selected and tables of results are given in Tables 4.01, 4.02 and 4.03. Pearson correlation coefficients were calculated using average scores for each group on each question. (see page A.2.52) 'Z' tests were used to test for significant differences.

COMPARISON OF REVISED V STANDARD (I)

TABLE 4.01

School / Test		Revised						Standard (I)					
		3	7	8	13	16	Total	2	8	11	13	16	Total
1	m	17.3	15.6	12.2	16.4	10.3	15.0	16.9	15.4	13.3	13.8	10.6	14.1
	σ	2.6	3.8	5.0	2.7	4.01	4.3	2.6	3.3	4.3	4.2	4.2	4.3
	n	51	87	38	15	19	210	37	36	89	18	20	200
2	m	14.6	14.8	9.3	11.9	8.2	13.1	14.9	12.7	12.7	7.7	8.2	12.4
	σ	4.6	4.3	4.6	4.2	4.3	4.5	4.3	4.5	4.5	5.1	2.8	4.8
	n	54	86	32	16	18	206	37	35	86	18	17	193
3	m	12.8	14.7	11.2	12.5	8.6	13.3	15.2	12.1	13.0	11.9	7.3	12.6
	σ	4.4	3.9	4.5	2.6	4.9	1.8	3.3	4.0	4.6	4.5	3.1	4.6
	n	55	80	32	15	14	196	36	33	88	17	19	193
4	m	11.8	10.3	11.2	-	-	10.9	8.5	6.7	8.6	-	-	8.2
	σ	4.8	4.7	4.9	-	-	4.8	3.8	4.0	4.9	-	-	4.5
	n	53	78	19	-	-	150	38	33	78	-	-	149
5	m	14.7	12.8	8.5	-	12.4	12.8	13.5	12.6	10.9	-	9.5	11.7
	σ	4.8	4.1	4.1	-	4.8	4.7	3.9	3.6	4.7	-	3.7	4.4
	n	51	70	20	-	14	155	35	29	70	-	16	150
'0' Grade	m	6.9	6.8	10.2	6.2	7.2	7.2	6.4	7.6	8.9	7.2	9.0	8.0
	σ	3.2	3.2	3.0	2.6	3.5	3.3	3.8	3.7	2.8	3.1	2.0	3.4
	n	56	78	19	17	17	187	37	32	77	17	15	178

	Revised	Standard
τ test 1 v '0'	0.53	0.85
τ test 5 v '0'	0.93	0.94

Schools 8, 13, 16 - groups matched on performance in Class 2

Schools 3, 7 matched with schools 2, 11 to give overall balance.

COMPARISON OF REVISED V STANDARD (II)

TABLE 4.02.

Test \ School		Revised					Standard (II)				
		8	10	12	16	Total	4*	5	10	12	Total
1	m	12.2	10.4	12.6	10.3	11.2	8.0	10.2	14.1	7.0	10.5
	σ	5.0	4.4	4.2	4.0	4.6	4.0	4.9	4.6	3.2	5.1
	n	38	45	16	19	118	70	72	22	16	110
2	m	9.3	-	10.6	8.2	9.3	4.8	9.3	-	5.8	8.9
	σ	4.6	-	3.8	4.3	4.4	3.1	4.7	-	1.3	4.3
	n	32	-	16	18	66	70	83	-	19	102
3	m	11.2	-	12.1	8.6	10.8	11.0	9.8	-	9.6	9.8
	σ	4.5	-	2.0	4.9	4.1	5.2	4.3	-	2.6	4.0
	n	32	-	16	14	62	61	82	-	19	101
4	m	11.2	-	5.0	-	8.4	6.7	5.0	-	7.3	5.3
	σ	4.9	-	3.2	-	5.2	3.5	3.9	-	1.3	3.7
	n	19	-	15	-	34	61	87	-	15	102
5	m	8.5	7.4	14.0	12.4	9.7	11.1	7.5	8.4	12.1	8.1
	σ	4.1	4.6	3.0	4.8	4.9	4.7	4.7	4.6	2.8	4.7
	n	20	28	12	14	74	66	76	15	9	100
'0' Grade	m	10.2	8.6	6.5	7.2	8.4	6.8	8.7	8.7	8.3	8.7
	σ	3.0	3.2	2.3	3.5	3.3	3.4	2.6	3.6	2.3	2.8
	n	19	21	11	17	68	69	74	23	10	107

	Revised	Standard
τ test 1 v '0'	0.04	.83
τ test 5 v '0'	0.84	.58

Schools 10, 12 - groups matched on performance in Class 2.

Schools 8, 16 matched with school 5 to give overall balance.

* School 4 not included as their early results were anomalous.

TABLE 4.03

COMPARISON OF SCHOOLS WHOLLY ON REVISED V SCHOOLS WITH GROUPS ON REVISED

School		All Revised					Matched with Standard (I)					Matched with Standard (II)		
Test		1	3	7	14	Total	2	8	13	16	Total	10	12	Total
1	m	16.0	17.3	15.6	11.3	14.7	15.8	12.2	16.4	10.3	13.7	10.4	12.6	11.0
	σ	3.7	2.6	3.8	4.8	4.6	3.6	5.0	2.7	4.01	4.7	4.4	4.2	4.4
	n	127	51	87	117	382	39	38	15	19	111	45	16	61
2	m	14.8	14.6	14.8	10.7	13.3	-	9.3	11.9	8.2	9.7	-	10.6	10.6
	σ	4.0	4.6	4.3	4.5	4.7	-	4.6	4.2	4.3	4.6	-	3.8	3.8
	n	123	54	86	110	373	-	32	16	18	66	-	16	16
3	m	15.4	13.8	14.7	11.7	13.9	-	11.2	12.5	8.6	10.9	-	12.1	12.1
	σ	3.9	4.4	3.9	4.5	4.4	-	4.5	2.6	4.9	4.2	-	2.0	2.0
	n	123	55	80	101	359	-	32	15	14	61	-	16	16
4	m	9.5	11.8	10.3	-	10.2	-	11.2	-	-	11.2	-	5.0	5.0
	σ	4.5	4.8	4.7	-	4.7	-	4.9	-	-	4.9	-	3.2	3.2
	n	124	53	78	-	255	-	19	-	-	19	-	15	15
5	m	13.5	14.7	12.8	9.4	12.4	11.6	8.5	-	12.4	10.8	7.4	14.0	9.4
	σ	4.7	4.8	4.1	4.4	4.9	4.6	4.1	-	4.8	4.7	4.6	3.0	5.1
	n	106	51	70	89	316	31	20	-	14	65	28	12	40
'0'	m	7.1	6.9	6.8	9.3	7.6	7.0	10.2	6.2	7.2	7.6	8.6	6.5	7.9
Grade	σ	3.4	3.2	3.2	2.8	3.3	3.7	3.0	2.6	3.5	3.5	3.2	2.3	3.0
	n	110	56	78	98	342	39	19	17	17	92	21.	11	32

All Revised

t test 1 V '0' = 0.95

t test 5 V '0' = 0.92

Matched with Standard I

test 1 V '0' = 0.49

test 5 V '0' = 0.96

Matched with Standard II

test 1 V '0' = 0.99

test 5 V '0' = 0.99

Discussion of Results

(a) Revised V Standard I

The results show no significant difference between the two groups. For Test 4 (calculations from equations) however, the differences are largest, but this difference does not seem to be maintained in the relevant parts of test 5.

(b) Revised V Standard II

These results show no significant difference between the two groups. The larger difference in Test 4 is again in evidence.

(c) Schools with all groups on Revised V Schools with matched groups

Data was too incomplete for any significant analysis to be made.

Summary

(1) Although lack of data prevented a complete matching of schools so that no significant differences were obtained, there are trends which suggest the success of the Revised route.

(a) the top mean score in each test and the top average performance in 'O' grade comes from the Revised group (except test 2 where top Revised mean = 14.8 - top Standard I mean = 14.9)

(b) Except for one school, the Revised group managed considerably better at the difficult concepts of the mole and calculations.

Both of the above may of course be due to nothing more than an inherent difference in ability of the groups. Given that approximately 50-60% of pupils follow at least a part S.C.E. course (based on data of Stirlingshire schools), they will on average have a V.R.Q. of approx 97-140$^{(20)}$ and although the V.R.Q. data obtained was very scant, it does show that our sample (V.R.Q. range 95-135 i.e. 110 $\pm$ 2σ) does not differ greatly from this

(2) Schools following the Revised route have not been disadvantaged because of less time for practice of formula writing etc. They have performed at least as well, if not better than those taught by the Standard routes.

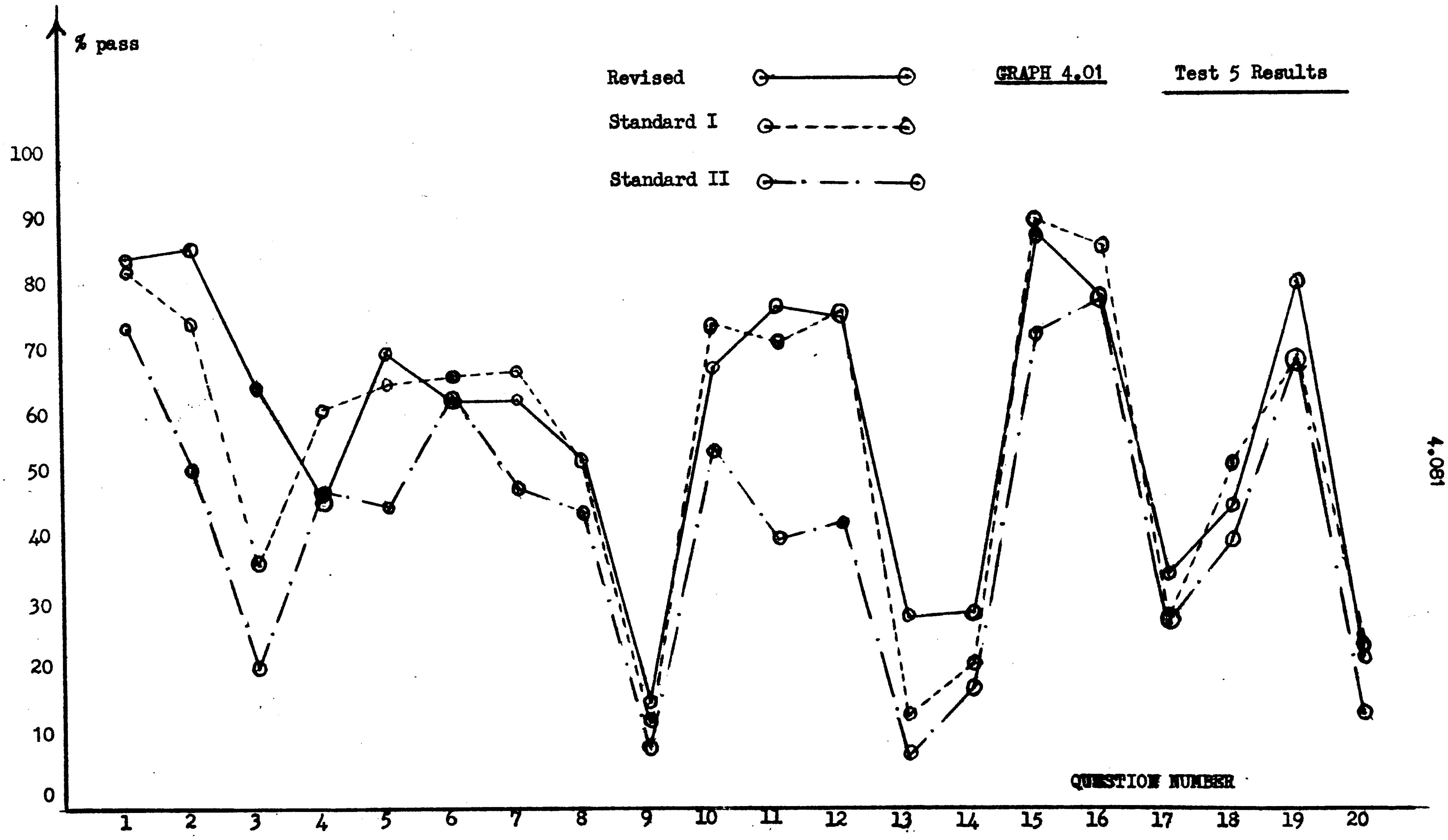
Detailed Analysis of Test 5

Unfortunately some schools failed to distinguish between their teaching groups, when filling in the more detailed mark sheet for test 5. This left considerably fewer results for analysis and consequently less significance can be attached to them. The results which could be identified are tabulated in Appendix page A.4.29. The percentage pass for each question was calculated and these results tabulated in Appendix page A.4.30. A graph of the mean percentage pass was drawn for all three groups - Revised, Standard I and Standard II, and this is shown in Graph 4.01.

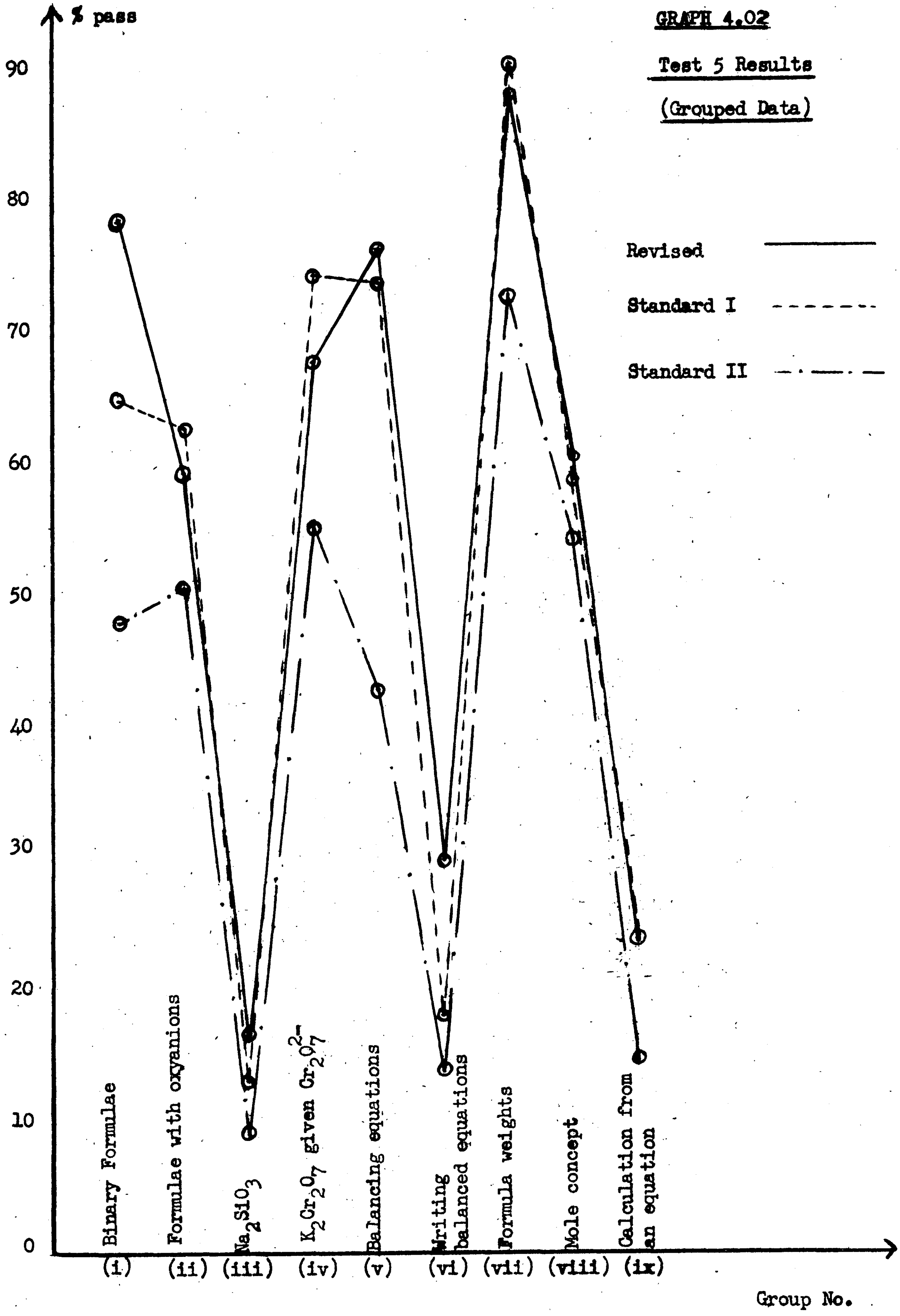
The results were then grouped together in broad topic areas viz.

	Group	Questions
(i)	Binary formulae	1 - 3
(ii)	Formulae including oxyanions	4 - 8
(iii)	Extrapolation to silicate	9
(iv)	Extrapolation given the formula for the oxyanions	10
(v)	Balancing equations	11 - 12
(vi)	Writing balanced equations from basic knowledge	13 - 14
(vii)	Calculation of formula weights	15
(viii)	The mole concept	16 - 19
(ix)	Calculations from an equation	20

and are tabulated in Appendix pageA.4.31. A graph of this grouped data was drawn for each of the three routes, and this is shown in Grahp 4.02.



GRAPH 4.01 Test 5 Results



GRAPH 4.02

Test 5 Results

(Grouped Data)

Discussion of Results

Although the groups did not start their 'O' grade course as matched groups, the product moment correlations* between the results of test 5 are very high.

All Questions

r_1 (Revised v Standard I) = 0.92

r_2 (Revised v Standard II) = 0.83

Grouped Questions

r_3 (Revised v Standard I) = 0.97

r_4 (Revised v Standard II) = 0.92

For many questions the % pass obtained by all three groups was very similar. It is therefore, those questions where there is large disagreement that will be of most interest.

(a) Questions 1 - 3. Binary formulae

	(1) $CaCl_2$	(2) Na_2O	(3) H_2S
Revised	84.9	86.5	64.9
Standard I	82.8	74.7	37.4
Standard II	70.4	52.1	21.8

It is significant that the interpretation of "sulphide" has once again proved a great problem especially to the Standard II group, although this does seem to be very school biased. It is unlikely that pupils would write Na_2O from recall, and as the results of 1 and 2 show only a relatively small decline, it is reasonable to assume that pupils are competent at handling the "mechanical rules". It would seem, therefore, that the problem with "sulphide" is the inclusion of oxygen.

There is the expected increase in performance in question 1 compared with Phase I, due to increased maturity, practice, etc.

---

* Calculated as on Page A.2.52.

(b) Questions 4 - 8. Formulae with oxyanions

	(4) $Sn(OH)_2$	(5) Na_2SO_4	(6) $BaCO_3$	(7) $Fe_2(SO_4)_3$	(8)NH_4NO_3
Revised	47.7*	70.2	62.8	62.8	53.8
Standard I	61.6	65.6	66.7	67.7	53.5
Standard II	48.6	46.5	63.4	49.3	45.8

* Depressed so low by the exceptionally low score of 1 school and the low score of another.

Q4. It could be that the problem here is the same as that detected in Phase I, namely leaving out the brackets, or possibly not interpreting Sn(II) correctly, although the results of question 7 would seem to rule this out.

The figures show a remarkable consistency in performance with "ammonium" providing a difficulty to all groups. Perhaps the error here is in writing NH_3^+ as was encountered in Phase I. The interpretation of Fe(III) does not appear to have presented too much difficulty.

(c) Question 9, 10. Extrapolations

	(9) Na_2SiO_3	(10) $K_2Cr_2O_7$ (given $Cr_2O_7^{2-}$)
Revised	16.6	68.0
Standard I	13.1	74.7
Standard II	9.2	55.6

Question 9 showed considerable school bias, with a range of 2.6% to 31.4% correct. The Revised group performed considerably better than either of the other two groups, and in fact the Revised group of school 8 who overall on test 5 were very much poorer than the Standard I group, performed considerably better in this question. The evidence would seem to support the idea that slow revelation of formulae/

formulae increases basic understanding and hence the ability to extrapolate, but it is not conclusive. The major issue remains however, that at best only 30% of pupils could answer this question and whether or not this sort of logical thinking should be included at '0' grade, merits further investigation.

That all groups performed better on question 10 when provided with the formulae $Cr_2O_7^{2-}$ than on average in questions 4 - 8, would seem to support the inclusion of the formulae of oxyanions in the data book(21) provided at the S.C.E. examinations. Obviously the mechanics of formulae writing can be mastered to a reasonable level of competency.

(d) Question 11, 12. Balancing Equations

	(11)	(12)
Revised	77.5	76.0
Standard I	71.7	76.8
Standard II	41.5	44.4

All schools showed good consistency in performance on these questions. Because of this it is possible that the majority of pupils can either balance equations well or not at all.

The difference between the Revised and Standard II groups for these two questions is the largest of all those in test 5 (except question 3). The evidence seems to indicate then that postponing the bulk of the equation writing and balancing until Class 4 leads to improved performance.

That two schools whose conditions were probably better than most (good equipment, constancy of staff, small classes etc.) could achieve 90-95% success on these questions, shows what can be achieved by ordinary pupils given these favourable conditions.

(e) Questions 13, 14. Writing Balanced Equations

(13) $2S + 3O_2 \longrightarrow 2SO_3$

(14) $3Pb(NO_3)_2 + 2AlCl_3 \longrightarrow 3PbCl_2 + 2Al(NO_3)_3$

	(13)	(14)
Revised	29.8	30.2
Standard I	14.1	22.2
Standard II	8.5	19.0

As was discovered in Phase I, pupils have great difficulty in translating an equation in words into those containing formulae. Schools have an 80%+ pass for writing formulae and for balancing equations, yet only achieve 30-40% pass on these questions.

(f) Question 15. Calculation of formula weights

	(15) $Ca_3(PO_4)_2$
Revised	88.6
Standard I	90.9
Standard II	73.2

All schools except one had very high % passes on this question. This is in agreement with the result from Phase I.

(g) Question 16 - 19. The mole concept.

(16) What is the weight of 2 moles of CH_3COOH

(17) How many moles of Cu are needed to make 1 mole of CuO

$$Cu + O_2 \longrightarrow 2CuO$$

(18) How many moles of NO_2 are produced by heating $\frac{1}{4}$ mole of $Pb(NO_3)_2$

$$2Pb(NO_3)_2 \xrightarrow{heat} 2PbO + 4NO_2 + O_2$$

(19) What weight of oxygen is there in 1 mole of $Cu(NO_3)_2$

	(16)	(17)	(18)	(19)
Revised	79.1	36.0	46.8	81.5
Standard I	86.9	29.3	50.5	69.7
Standard II	78.9	28.9	41.5	69.0

The high pass levels in 16 and 19 confirm the result from question 15. It seems likely that the partly balanced equation in question 17 was misleading. Introducing fractions and proportion leads to a fall in results in all schools. This, however, is a considerable improvement on the results from Phase I, which is possibly due to increased maturity and practice.

(h) Question 20. Calculation from equation.

What weight of Al would react completely with 80g of CuO.

$$Al + CuO \longrightarrow Al_2O_3 + Cu$$

	(20)
Revised	23.7
Standard I	24.2
Standard II	14.8

With pass levels as low as 5% and a maximum of only 40% for any group, this type of question does seem to be beyond the majority of candidates at '0' grade.

Summary

(1) The basic idea of 'organic' first can produce good results for formula writing, balancing equations and the mole concept.

(2) The major advantages of this organic first approach are in:-

- (i) writing binary formulae, especially not confusing IDE with ITE.
- (ii) no need for balancing equations until Class 4.

(3) From the data available there would appear to be no significant difference in performance of the Revised and Standard II, groups. It is perhaps of note, though, that a lot of pupils following the Revised order have achieved a higher level of consistency in formula writing and calculations than those in the Standard groups. The evidence is of course not conclusive.

Validity of Tests

To see whether performance in these tests was related to overall chemical ability, product moment correlations between each test and the '0' grade results were calculated. (As on page A.2.52)

r_5 (test 1 v '0' grade)	0.64	
r_6 (test 2 v '0' grade)	0.42	
r_7 (test 3 v '0' grade)	0.46	
r_8 (test 4 v '0' grade)	.01	(lot of scores missing)
r_9 (test 5 v '0' grade)	.80	

Although these favourable correlations seemed to suggest that at least performance in the tests was related to overall chemical ability (as measured by the '0' grade examination) it was decided to examine individual pupil performance throughout the series of tests. It was only possible at this late stage to obtain information as detailed as this from school 3.

The results are tabulated in appendix page A.4.32-A.4.33. Product moment correlations were calculated giving

r_{10} (Total v '0' grade) = 0.68

r_{11} (test 5 v '0' grade) = 0.68

Using the same results Spearman rank correlations were also calculated comparing rank order in each test with that obtained at '0' grade.

Test 1 V '0' grade	0.37
Test 2 V '0' grade	0.57
Test 3 V '0' grade	0.51
Test 4 V '0' grade	0.67
Test 5 V '0' grade	0.62

These results would seem to indicate that performance in the areas under test is related to overall chemical ability as measured in the '0' grade examination. It is not surprising that the lowest correlation is for binary formulae which demand the least conceptual development for mastery.

Pupil Questionnaire - Phase II (See Pages 2.17 and 4.01)

Construction

It was decided to limit the number of questions to those specifically on the topics under investigation in order to concentrate pupils attention on to them. The number of categories of answer were also reduced to 3 to make evaluation easier for them. The complete questionnaire is given in appendix page A.4.34.

Administration

Pupils were asked to complete the questionnaire after they had sat test 5.

Results

Not every school differentiated between their teaching groups when returning the questionnaires. This meant that some of the data was unusable. The results that could be identified are given in appendix page A.4.35.

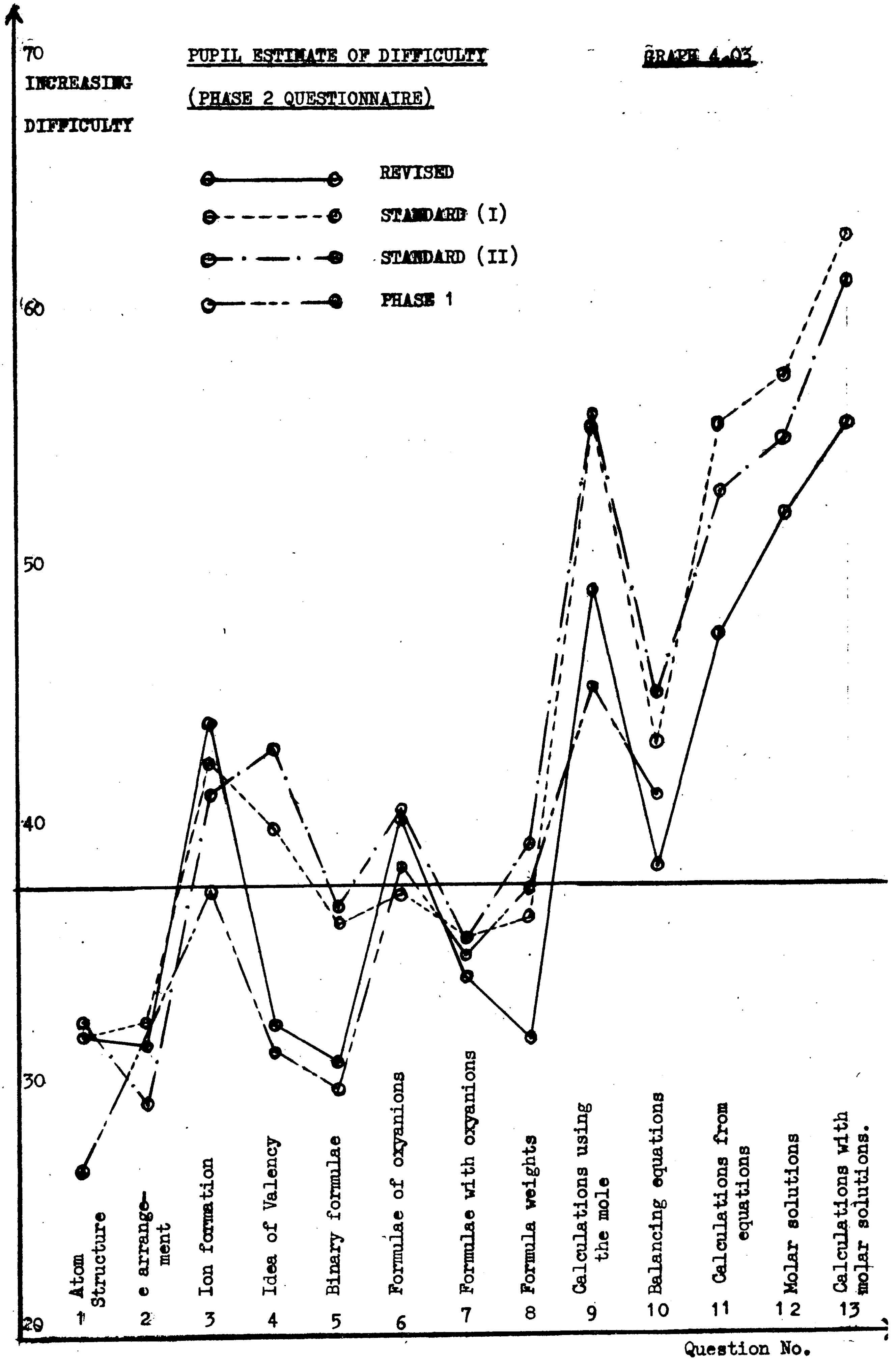
A similar marking scheme to that used in Phase I was employed (See pages 2.17 and A.2.53) where

Easy to grasp = 1
Hard to grasp = 2
Never really grasped = 3

(A topic that was thought by pupils to be of reasonable difficulty should have a mean score of 1.5). The mean scores were then multiplied by 25 to give a range of 25 - 75.

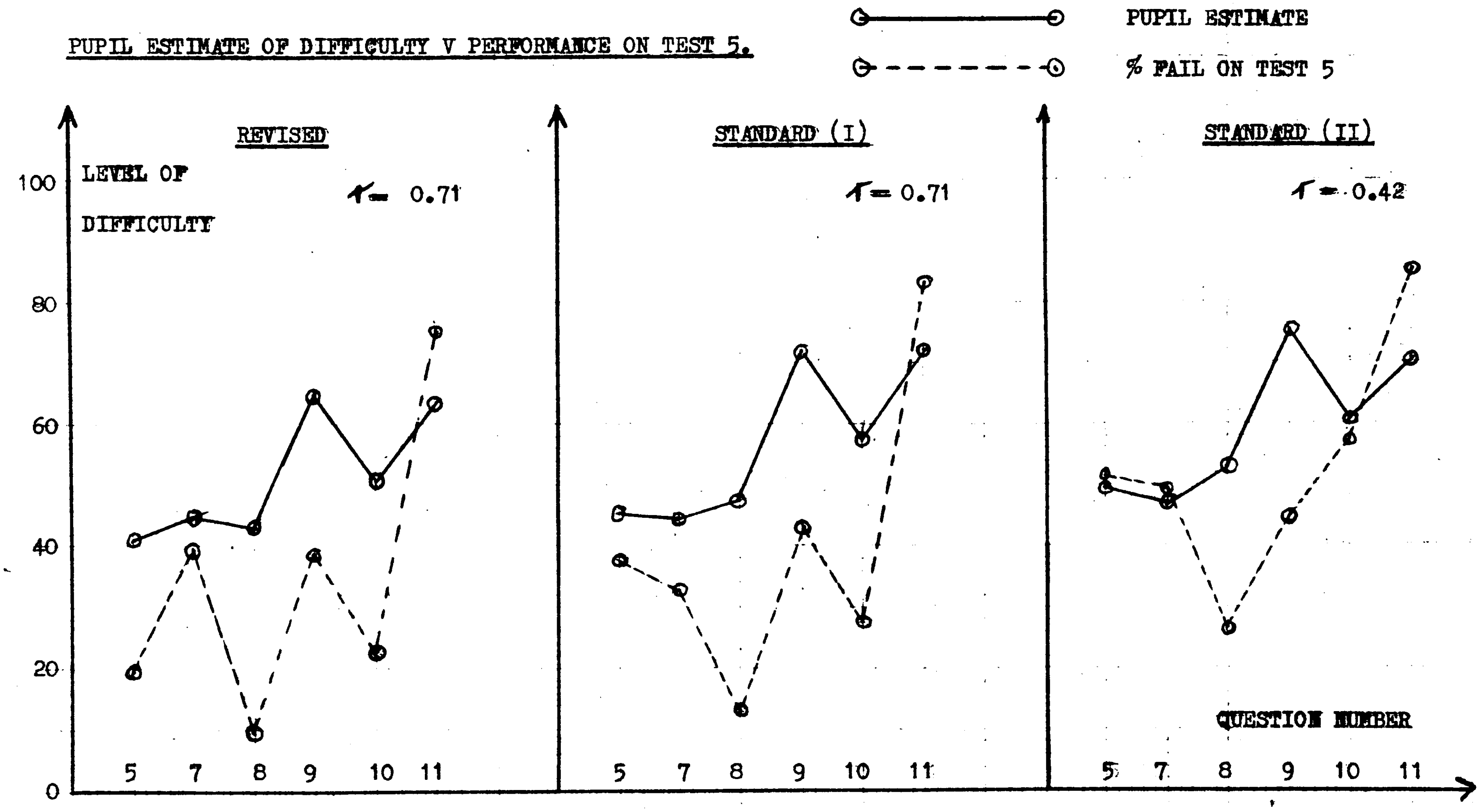
A graph was then drawn of the results from the three teaching groups (Graph 4.03.)

The means of the corresponding questions from the questionnaire in Phase I were multiplied by a factor of $\frac{1.5}{2}$ to give them approximately the same range as the results from Phase II and these results


PUPIL ESTIMATE OF DIFFICULTY
(PHASE 2 QUESTIONNAIRE)
GRAPH 4.03
70
INCREASING
DIFFICULTY
60
50
40
30
20
REVISED
STANDARD (I)
STANDARD (II)
PHASE 1
1 Atom Structure
2 e arrangement
3 Ion formation
4 Idea of Valency
5 Binary formulae
6 Formulae of oxyanions
7 Formulae with oxyanions
8 Formula weights
9 Calculations using the mole
10 Balancing equations
11 Calculations from equations
12 Molar solutions
13 Calculations with molar solutions.
Question No.

GRAPH 4.04

PUPIL ESTIMATE OF DIFFICULTY V PERFORMANCE ON TEST 5.



added to the graph.

Product moment correlations were calculated as follows:-(See page A.2.52)

r_1 (Revised V Standard I) = 0.94

r_2 (Revised V Standard II) = 0.90

r_3 (Revised V Phase I) = 0.82

r_4 (Standard I V Phase I) = 0.80

r_5 (Standard II V Phase I) = 0.81

r_6 (Standard I V Standard II) = 0.97

As can be seen from the extremely high correlations the questionnaires seem to be consistent.

Whenever possible questions were matched with those in Test 5 (grouped data) - scores in test 5 being taken as (100 - % pass) to give a measure of the degree of difficulty. These results are tabulated in appendix page A.4.36.

Graphs were drawn of pupil response v % fail in the grouped data from test 5. (Graph 4.04)

Discussion of Results

(a) pupil responses

As can be seen from the graph, the responses from the 3 groups are very consistent. The pattern that emerges is

Revised group $<$ Standard II OR Standard I
(With II $<$ I on the Application level Questions)

These differences, however, could well be due to a basic difference in performance of the groups as seen in tests 1 - 5. They are by no means matched groups.

It is where there are major breaks from this pattern that will be of most interest

(i) Question (2) - electron arrangement

Standard II group lowest - probably due to sampling errors.

(ii) Question (3) - formation of ions.

Revised group found this more difficult than the other 2 groups. This could be due to the emphasis placed on the "covalent" approach and the lack of practice with ions and ionic formulae.

(iii) Questions 5 & 7. - Binary formulae and Ionic formulae

The Revised group thought that formulae of the type Na_2CO_3 more difficult to learn than those of the type NaCl. Both Standard groups thought the reverse. This difference was borne out in the performance of these schools on Test 5.

(iv) Questions 11, 12, 13 - Calculations, molar solutions, calculations with molar solutions.

The Standard I group thought these most difficult but this can not be significant when all the schools in the 3 groups greatly underestimated the level of difficulty of these questions.

(b) Pupil responses V performance in Test 5.

(i) All pupils over estimated the difficulty of these topics.

(ii) Although pupils all thought that calculations involving the mole were very difficult, their performance on test 5 on this topic was no worse than that on ionic formulae.

(iii) All Pupils underestimated the difficulty of calculations from equations.

(iv) As was discovered in Phase I, calculating formula weights presented far less difficulty than anyone estimated.

(v) Pupils at the end of Class 4 were able to make a more consistent judgement of difficulty than those who were tested in Phase I. when in Class 3.

GENERAL CONCLUSIONS

(1) From the results obtained, it would seem that generally the Revised group found the course easier than the other groups did, although this may be a function of their overall ability.

(2) Pupils were consistent judges of difficulty, even if they over estimated. The fact that pupils in Class 4, after exam hurdles over estimated a difficulty, while pupils in Class 3 underestimated difficulty (see Graph 2.02 page 2.172) is perhaps significant. Yet pupils still underestimate the difficulty of calculations from equations.

(3) The data obtained was too incomplete to make any valid judgement on the other two objectives given on page 4.02 viz.

(i) Does having the school only partly committed to the Revised order (i.e. with matched groups) affect significantly the performance of either group with respect to schools wholly committed?

(ii) Does the gradual revelation of equations have a significant advantage over 'en bloc' revelation when pupils follow the 'organic first' teaching order?

List of schools who took part in the evaluation of the revised teaching order.

School No.	Description of the School
1	6 year selective in Central Scotland
2	6 year selective in a developing industrial area
3	6 year comprehensive in Glasgow overspill area
4	6 year Roman Catholic comprehensive in Central Scotland
5	6 year comprehensive in a large city.
7	6 year comprehensive in a rural area.
8	6 year comprehensive on the East Coast.
9	Developing 6 year comprehensive in a New Town.
10	6 year Roman Catholic comprehensive in the West of Scotland.
11	6 year comprehensive in a large town with an average intake.
12	6 year comprehensive in the North.
13	6 year comprehensive in an Island community.
14	6 year comprehensive in the suburbs of a large town in West Scotland.
15	6 year comprehensive in a large town in West Scotland.
16	New, developing, 6 year comprehensive in a large city.

Test 1

University of Glasgow

Research in Chemical Education

In question 1 and 2 tick the correct answer (or answers)

1. Atoms of the same element always have the same number of

A. Protons ☐
B. Neutrons ☐
C. Electrons ☐

2. An atom of $^{56}_{26}\text{Fe}$ has

	Protons	Neutrons	Electrons	Tick here
A	26	56	26	
B	30	26	26	
C	26	30	26	
D	26	30	26	

In the following questions write your answer in the space provided

3. Which kind of bond

A - Electrovalent B - Covalent

would you expect between the following pairs of atoms

(i) S, S ☐
(ii) K, Br ☐
(iii) Ca, O ☐

4. Which elements are present in the following compounds

(i) Hydrogen Sulphide ....
(ii) Aluminium Bromide ....
(iii) Magnesium Nitride ....
(iv) Sodium Hydride ....

5. Write the formulae for the following compounds

(i) Potassium Bromide ....
(ii) Hydrogen Sulphide ....
(iii) Carbon chloride ....
(iv) Aluminium Oxide ....
(v) Nitrogen Hydride ....

6. A pupil wrote the following formulae in his book. Put a cross against those you think he got <u>wrong</u>

(i) HO_2	(ii) H_3N	(iii) $MgCl$	(iv) P_3O_2	(v) HI

Now write the correct formulae for 2 of the ones he got wrong.

A. ....

B. ....

Test 1

Question

1 An easy starter, but testing understanding of atomic structure

2 Typing error made responses C & D the same. This was picked up by teachers and the papers changed accordingly.

3 Polar - covalent bonding was left out deliberately to avoid confusion in those schools where this was not taught.

4 This was included because of the poor performance on a similar question in Phase I.

5 These are relatively straight forward and involve no cancellations e.g. $C_2O_4 \longrightarrow CO_2$.

6 This tests understanding of formula format.

Test 2.

Research in Chemical Education

Answer all the questions in the space provided

1. Complete the following table. The first one has been done for you

Name of the ion	Elements Present	Formula	Valency (Combining power)
Phosphate	Phosphorus, Oxygen	PO_4	3
Sulphate			
Carbonate			
Nitrate			
Hydroxide			
Ammonium	Nitrogen, Hydrogen		

2. Write the formulae for the following compounds in the spaces provided.

(a) Sodium Nitrate ....

(b) Magnesium Sulphate ....

(c) Aluminium Hydroxide ....

(d) Calcium Phosphate ....

(e) Ammonium Carbonate ....

(f) Sulphuric acid ....

3. A pupil wrote the following formulae in his note-book. Put a cross beside those you think he got wrong. The charges on the ions were left out on purpose.

(a)	Nitric acid	H_2NO_4	☐
(b)	Iron Sulphide	FeS	☐
(c)	Lithium Phosphate	Li_3PO_4	☐
(d)	Potassium Carbonate	P_3CO_2	☐
(e)	Calcium Hydroxide	$CaOH_2$	☐

Now write the correct formula for 2 of those that you think he got wrong

(i) .... (ii) ....

4. Vertical columns in the Periodic Table contain families. of elements in which the elements are similar to one another

Remembering this, write the formulae for:-

(a) Sodium Silicate ....

(b) Sodium Selenate ....

Test 2

Question

1 Phosphate was chosen as the example because many schools do not include this ion. The elements present in 'ammonium' were also given as there was no way for pupils to reason this out.

2 The formulae all use the common anions as in question 1. No extrapolation is required.

3 This again tests understanding of formulae format e.g. $CaOH_2$, knowledge of symbols and 'cancellation'(e.g. FeS)

4 The more able pupils should be able to extrapolate.

A.4.08

Test 3

University of Glasgow

Research in Chemical Education

Answer all the questions in the spaces provided. Use the following list of approximate atomic weights where necessary.

H = 1 C = 12 N = 14 O = 16 Na = 23

Al = 27 S = 32 Cl = 35.5 Fe = 56

1. Write the formulae for
   - (a) sodium sulphide ....
   - (b) sodium sulphate ....
   - (c) Iron(III) carbonate ....
   - (d) ammonium nitrate ....

2. Calculate the formula weights for the following showing your working
   - (a) NaCl ....
   - (b) Al_2O_3 ....
   - (c) $FeSO_4$ ....
   - (d) $(NH_4)_2SO_4$ ....
   - (e) $Na_2CO_3IOH_2O$ ....

3. When hydrogen and oxygen are sparked together, water (H_2O) is made. What weight of water would be obtained from sparking a mixture of 80 g. of hydrogen and 80 g. of oxygen. Place a tick opposite the correct answer.
   - (a) 160 g. ☐
   - (b) 95 g. ☐
   - (c) 90 g. ☐
   - (d) 18 g. ☐

4. What is the weight of 1 mole of glucose ($C_6H_{12}O_6$)? ....

5. What is the approximate weight of 1 mole of protons?............

6. One mole of $CaCl_2$ contains
   - (a) 1/3 mole of Ca^{2+} ions and 2/3 mole of Cl^- ions ☐
   - (b) 1 mole of Ca^{2+} ions and 1 mole of Cl_2^- ions ☐

(c) $\frac{1}{2}$ mole of Ca^{2+} ions and $\frac{1}{2}$ mole Cl_2^- ions. ☐

(d) 1 mole of Ca^{2+} ions and 2 moles Cl^- ions ☐

(Place a tick against the correct answer.)

7. What is the maximum number of moles of chlorine molecules that theoretically could be obtained from 36.5 g. of hydrogen chloride?

....

Test 3.

Question

1 Revision of formulae. Testing distinction between IDE and ITE - a problem highlighted in Phase I.

2 These become progressively harder, testing understanding of formulae of increasing complexity.

3 A difficult question to test understanding of combination in fixed proportions.

4 A straight forward question on the relationship between formula weight and the mole.

5 As for question 4, but more difficult.

6 Results of objective tests given by the author in schools (1) and (3), had shown that the interpretation of formulae into moles of ions present was a problem.

7 A fairly difficult question on the mole concept involving a further step to consider Chlorine molecules, thus bringing in fractions.

Test 4.

University of Glasgow

Research in Chemical Education

You may need to use the following atomic weights.

H = 1   N = 14   C = 12   O = 16.

Asnwer all the questions in the spaces provided.

1. Rewrite the following word equations using correct symbols and formulae. There is no need to balance the equations in this question.

(a) sodium + water → sodium hydroxide + hydrogen

...... + ... → .... + ...

(b) Iron(II) sulphide + nitric acid → Iron(II) nitrate + hydrogen sulphide

.................+ .... → .... + ...

2. Balance the following equations

(a) $Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$

(b) $Al + O_2 \rightarrow Al_2O_3$

(c) $Al + CuSO_4 \rightarrow Al_2(SO_4)_3 + Cu$

(d) $Pb(NO_3)_2 \xrightarrow{heat} PbO + NO_2 + O_2$

3. Write balanced equations for the following reactions:

(a) Zinc on hydrochloric acid to give hydrogen

....

(b) Hydrochloric acid on calcium carbonate to give carbon dioxide

....

4. How many moles of oxygen will be used up when 2 moles of ethane (C_2H_6) is completely burnt?

$$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$$

A	4	
B	5	
C	6	
D	7	

Tick the correct answer

5. A pupil was calculating the weight of hydrogen needed to react completely with 84 g. of Nitrogen gas to form ammonia and he made a number of mistakes.

Rewrite the equation and the calculation underneath, correcting all his mistakes.

Pupil's version:-

$$2N + 4H_2 \rightarrow 2NH_4$$

Therefore 2 moles of Nitrogen reacts with 8 moles of Hydrogen
Therefore 14 g. of Nitrogen reacts with 8 g. of Hydrogen
Therefore 84 g. of Nitrogen reacts with $\frac{14 \times 8}{84}$ g. of Hydrogen

= 10 g. Hydrogen

Corrected version:-

( ) + ( ) → ( )

Therefore ( ) moles of Nitrogen reacts with ( ) moles of Hydrogen

Therefore ( )g. of Nitrogen reacts with ( )g. of Hydrogen

Therefore 84g. of Nitrogen reacts with $\frac{\quad}{\quad}$ g. of Hydrogen

= ( ) g. of Hydrogen

1. Phase I had revealed translational difficulties in equations. This served to test formula writing in an equation content.

2. Although some pupils had shown in Phase I that they used only equations involving separate ions, these 'covalently' written equations were chosen deliberately. The pupils who would have difficulty with this format were catered for by instructing teachers to rewrite the equations if necessary.

3. To test equation writing without testing too deeply other chemical knowledge, two straight forward examples were chosen that most pupils should be familiar with, the reactions being met previously in Class 2.

4. Pupils had shown in Phase I a lack of understanding of when to balance equations. Two moles of ethane were chosen to eliminate fractions.

5. This question provided the pupil with a backbone to work on for the difficult task of proportion and it tests

(i) formula writing
(ii) balancing equations
(iii) formula weights
(iv) mole concept - moles from equations
(v) proportion.

Test 5 Research in Chemical Education

You may need to use the following atomic weights

H = 1 C = 12 N = 14 O = 16

Al = 27 P = 31 Ca = 40 Cu = 64

Answer all the questions in the spaces provided

(A) Write correct formulae for the following:-

(1) calcium chloride ....
(2) sodium oxide ....
(3) hydrogen sulphide ....
(4) tin (II) hydroxide ....
(5) sodium sulphate ....
(6) barium carbonate ....
(7) iron (III) sulphate ....
(8) ammonium nitrate ....
(9) magnesium silicate ....
(10) potassium dichromate ....
(the dichromate ion is $Cr_2O_7^{2-}$)

(B) Balance the following equations:-

(11) $Li + H_2O \longrightarrow LiOH + H_2$

(12) $Mg + Al_2(SO_4)_3 \longrightarrow MgSO_4 + Al$

(C) Write a balanced equation for each of the following chemical reactions:-

(13) Making sulphur trioxide from its elements

(14) Precipitating lead chloride from lead (II) nitrate solution by adding aluminium chloride.

(D) (15) What is the formula weight of $Ca_3(PO_4)_2$?

A	B	C	D
215	248	279	310

(16) What is the weight of 2 moles of CH_2COOH ?

A	B	C	D
240g	120g	60g	44g

(17) How many moles of Cu are needed to make 1 mole of CuO ?

$$Cu + O_2 \longrightarrow 2\,CuO$$

A	B	C	D
$\frac{1}{4}$	$\frac{1}{2}$	1	2

(18) How many moles of NO_2 are produced by heating $\frac{1}{4}$ mole of $Pb(NO_3)_2$?

$$2Pb(NO_3)_2 \xrightarrow{heat} 2PbO + 4NO_2 + O_2$$

A	B	C	D
$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1

(19) What weight of oxygen is there in 1 mole of $Cu(NO_3)_2$?

A	B	C	D
96g	48g	24g	16g

(20) What weight of Al would react completely with 80g of CuO ?

$$Al + CuO \longrightarrow Al_2O_3 + Cu$$

A	B	C	D
18g	27g	36g	54g

Formula Writing

A. 1 - 3 Straightforward binary formulae.

4 tests understanding of the meaning of (II) etc. in formulae .

5 - 8 Formulae with oxyanions.

9 An extrapolation.

10 As the formulae for oxyanions were to be provided at S.C.E. exams in 1973(21), this was included to see whether pupils could make correct use of this information.

Balancing Equations

B. 11 Used to test the idea of doubling to remove fractions.

12 a 3 : 2 ratio - usually more difficult.

C. 13, 14 No further chemical knowledge is required other than formula writing, and balancing. These should help to give a good spread of marks as they are slightly more difficult.

Formula Weights and the mole

D. 15 A straightforward question to test basic understanding.

16 This question moves one stage further than 15 and tests understanding of the 'mole'.

17 This equation was deliberately not balanced to test understanding of the need for balancing.

18 This equation was used in order to involve fractions in proportion thus making it more difficult (as shown by K. Urquhart in her work at Glasgow(17)).

19 A straightforward example to test understanding of the processes to obtain weights from formulae.

20 An example of a calculation based on an equation that is difficult, but in which the arithmetic is as simple as

possible. Failure should be due to a lack of understanding of:-

(i) proportion

(ii) the mole concept.

<u>Marking Brief</u> <u>Test 1.</u>

(All answers either right or wrong, no partial marks).

1. A and C 2

2. D. 1

3. (i) B (ii) A (iii) A 3

4. (i) Hydrogen ; Sulphur;
 (ii) Aluminium ; Bromine;
 (iii) Magnesium ; Nitrogen;
 (iv) Sodium ; Hydrogen; (4 x 1) 4

5. (i) KBr
 (ii) H_2S
 (iii) CCl_4
 (iv) Al_2O_3
 (v) NH_3 (5 x 1) 5

(Accept a correct equivalent if you use a different format. Do not insist on charges on the ions.)

6. (i); (iii); (iv); 3

Give 1 mark for each correct answer and subtract 1 mark for each incorrect answer - minimum mark zero.

H_2O; $MgCl_2$; P_2O_3 (any 2) 2

(Accept a correct equivalent. Do not insist on charges on the ions.)

TOTAL 20

A.4.19

Marking Brief   Test 2

(All answers either right or wrong, no partial marks.)

1.	Sulphur, Oxygen	(½)	SO_4	(½)	2	(½)		
	Carbon, Oxygen	(½)	CO_3	(½)	2	(½)		
	Nitrogen, Oxygen	(½)	NO_3	(½)	1	(½)		
	Oxygen, Hydrogen	(½)	OH	(½)	1	(½)		
			NH_4	(½)	1	(½)	(14 x ½)	7

(Do not insist on charges on the ion, the correct proportions are sufficient.)

2. (a) $NaNO_3$

(b) $MgSO_4$

(c) $Al(OH)_3$

(d) $Ca_3(PO_4)_2$

(e) $(NH_4)_2CO_3$

(f) H_2SO_4 (6 x 1) 6

(Accept a correct equivalent if you use a different format. Do not insist on charges on the ions.)

3. a; d; e; (3 x 1) 3

Any 2 from HNO_3; K_2CO_3; $Ca(OH)_2$ 2

(Accept a correct equivalent)

4. (a) Na_2SiO_3 (b) Na_2SeO_4 2

(Accept a correct equivalent)

TOTAL 20

Marking Brief **Test 3**

1. (a) Na_2S
   (b) Na_2SO_4
   (c) $Fe_2(CO_3)_3$
   (d) NH_4NO_3 (4 x 1) 4

   Accept equivalent formulae but do not insist on correct ion charges, only on correct proportions.

2. (a) $23 + 35.5 = 58.5$
   (b) $(2 \times 27)+(3 \times 16) = 102$
   (c) $56 + 32 +(4 \times 16) = 152$
   (d) $2(14 + 4) + 32 +(4 \times 16) = 132$
   (e) $(2 \times 23) + 12 +(3 \times 16)+(10 \times 18) = 286$
   (5 x 2) 10

   Give 2 marks for a correct answer and 1 mark if the answer is wrong but the working is correct (i.e. there has only been an arithmetical error.)

3. C 1

4. 180 g. 2

   Score 1 if units wrong.
   Score 1 if error is purely arithmetical (working will need to be evident).

5. 1 g. 1

   Units essential.

6. D 1

7. $\frac{1}{2}$ 1

TOTAL 20

A.4.21

Marking Brief Test 4

1. (a) $Na + H_2O \rightarrow NaOH + H_2$

(b) $Fe\ S + HNO_3 \rightarrow Fe(NO_3)_2 + H_2S$

Do not insist on charges on ions. Accept correct alternative formulae.

right or wrong (8 x ½) 4

2. (a) $Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

(b) $4Al + 3O_2 \rightarrow 2Al_2O_3$

OR

$2Al + 1\frac{1}{2}O_2 \rightarrow Al_2O_3$

(c) $2Al + 3CuSO_4 \rightarrow Al_2(SO_4)_3 + 3Cu$

(d) $2Pb(NO_3)_2 \xrightarrow{heat} 2PbO + 4NO_2 + O_2$

right or wrong (4 x 1) 4

3. (a) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

(b) $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$

1 mark for correct formuale - right or wrong

1 mark for correct proportions - right or wrong

(2 x 2) 4

4. D. 2

5. $N_2 + 3H_2 \rightarrow 2NH_3$ 2 marks

(1 mark if gets correct formulae)

Therefore 1 mole $N_2 \rightarrow$ 3 moles H_2 1 mark

" 28 g. $N_2 \rightarrow$ 6 g. H_2 1 mark

" 84 g. $N_2 \rightarrow \frac{6 \times 84}{28}$ g. H_2

= 18 g. 1 mark 6

TOTAL 20

If formulae or equations are wrong, but calculation is correct on the basis of the wrong equation, give the 4 calculation marks.

Marking Brief — Test 5

A.	(1)	$CaCl_2$		
	(2)	Na_2O		
	(3)	H_2S	(Accept other correct methods)	
	(4)	$Sn(OH)_2$		
	(5)	Na_2SO_4		
	(6)	$BaCO_3$		
	(7)	$Fe_2(SO_4)_3$		
	(8)	NH_4NO_3		
	(9)	$MgSiO_3$		
	(10)	$K_2Cr_2O_7$	(10 x 1)	10
B.	(11)	$2Li + 2H_2O \longrightarrow 2LiOH + H_2$		1
	(12)	$3Mg + Al_2(SO_4)_3 \longrightarrow 3MgSO_4 + 2Al$		1
C.	(13)	$2S + 3\ O_2 \longrightarrow 2SO_3$		1
	(14)	$3Pb(NO_3)_2 + 2AlCl_3 \longrightarrow 3\ PbCl_2 + 2Al(NO_3)_3$		1
D.	(15)	D.		1
	(16)	B.		1
	(17)	C.		1
	(18)	C.		1
	(19)	A.		1
	(20)	A.		1
			TOTAL	20

Mark each question as right or wrong.

A. 4.23

Marks Return Sheet

University of Glasgow

Research in Chemical Education

School:

Test Number:

Teaching Order (Revised/Standard)

Number of Pupils	Mark
	0 - 4
	5 - 9
	10 - 14
	⩾ 15

Total No. of pupils ....

Median: ....

Mean: ....

Signed: ....
(Principal Teacher)

Test 5.

MARK RETURN SHEET

Number	Number of correct responses
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

School : ....

Signed : ....

Date : ....

V.R.Q. Data

	Revised	Standard (I)	Standard (II)
mean	110.8	110.4	115.1
σ	7.6	9.5	8.6
n	340	67	18
No. of Schools	6	2	1

A.4.26

Revised Group Results Tests 1 - 5

Test	School Score	1	2	3	7	8	9	10	12	13	14	15	16	Total
1	0-4	3	0	1	1	2	0	3	1	0	8	0	1	20
	5-9	4	3	0	6	10	2	17	1	0	36	3	7	89
	10-14	27	9	3	21	13	3	18	10	4	43	12	9	172
	$\geqslant 15$	93	27	47	59	13	11	7	4	11	30	47	2	351
	n	127	39	51	87	38	16	45	16	15	117	62	19	632
	m	16.0	15.8	17.3	15.6	12.2	15.5	10.4	12.6	16.2	11.3	16.3	10.3	14.3
	σ	3.7	3.6	2.6	3.8	5.0	4.1	4.4	4.2	2.7	4.8	3.2	4.0	4.6
2	0-4	0		1	0	4			0	0	5		2	12
	5-9	15		9	15	14			7	5	44		12	121
	10-14	39		11	18	10			7	7	39		2	136
	$\geqslant 15$	69		33	33	4			2	4	22		2	189
	n	123		54	86	32			16	16	110		18	458
	m	14.8		14.6	14.8	9.3			10.6	11.9	10.7		8.2	12.9
	σ	4.0		4.6	4.3	4.6			3.8	4.2	4.5		4.3	4.8
3	0-4	3		3	0	2			0	0	7		2	17
	5-9	5		3	9	7			1	1	20		8	54
	10-14	37		25	27	18			14	12	51		2	186
	$\geqslant 15$	78		24	44	5			1	2	23		2	179
	n	123		55	80	32			16	15	101		14	436
	m	15.4		13.8	14.7	11.2			12.1	12.5	11.7		8.6	13.5
	σ	3.9		4.4	3.9	4.5			2.0	2.6	4.5		4.9	4.4
4	0-4	18		3	7	2			7					37
	5-9	40		14	30	4			7					95
	10-14	54		21	27	9			1					112
	$\geqslant 15$	12		15	14	4			0					45
	n	124		53	78	19			15					289
	m	9.5		11.8	10.3	11.2			5.0					10.0
	σ	4.5		4.8	4.7	4.9			3.2					4.8
5	0-4	3	2	2	2	3		7	0		9		0	28
	5-9	20	7	7	10	9		14	0		42		5	114
	10-14	34	15	10	37	7		5	8		27		4	147
	$\geqslant 15$	49	7	32	21	1		2	4		11		5	132
	n	106	31	51	70	20		28	12		89		14	421
	m	13.5	11.6	14.7	12.8	8.5		7.4	14.0		9.4		12.4	11.9
	σ	4.7	4.6	4.8	4.1	4.1		4.6	3.0		4.4		4.8	5.0

A.4.27

Standard Groups Results Tests 1 - 5

		STANDARD I						STANDARD II				
Test	School Score	2	8	11	13	16	Total	4	5	10	12	Total
1	0-4	0	0	1	0	2	3	12	8	1	3	24
	5-9	1	1	18	3	4	27	35	27	2	10	74
	10-14	5	14	34	7	12	72	20	23	8	3	54
	≥ 15	31	21	36	8	2	98	3	14	11	0	28
	n	37	36	89	18	20	200	70	72	22	16	180
	m	16.9	15.4	13.3	13.8	10.6	14.1	8.0	10.2	14.1	7.0	9.5
	σ	2.6	3.3	4.3	4.2	4.2	4.3	4.0	4.9	4.6	3.2	4.8
2	0-4	1	2	1	5	1	10	36	13		0	49
	5-9	3	4	23	8	5	43	29	31		19*	79
	10-14	11	18	31	3	11	74	5	29		0	34
	≥ 15	22	11	31	2	0	66	0	10		0	10
	n	37	35	86	18	17	193	70	83		19	172
	m	14.9	12.7	12.7	7.7	8.2	12.4	4.8	9.3		5.8	7.2
	σ	4.3	4.5	4.5	5.1	2.8	4.8	3.1	4.7		1.3	4.4
3	0-4	0	1	3	1	3	8	8	10		0	18
	5-9	1	6	17	3	12	39	15	24		9	48
	10-14	15	19	34	9	4	81	23	41		10	74
	≥ 15	20	7	34	4	0	65	15	7		0	22
	n	36	33	88	17	19	193	61	82		19	162
	m	15.2	12.1	13.0	11.9	7.3	12.6	11.0	9.8		9.6	10.2
	σ	3.3	4.0	4.6	4.5	3.1	4.6	5.2	4.3		2.6	4.5
4	0-4	4	10	18			32	17	49		0	66
	5-9	21	16	26			63	31	25		14	70
	10-14	11	6	26			43	13	12		1	26
	≥ 15	2	1	8			11	0	1		0	1
	n	38	33	78			149	61	87		15	163
	m	8.5	6.7	8.6			8.2	6.7	5.0		7.3	5.8
	σ	3.8	4.0	4.9			4.5	3.5	3.9		1.3	3.7
5	0-4	0	0	8		2	10	5	25	3	0	33
	5-9	5	5	14		4	28	19	23	6	1	49
	10-14	17	17	36		10	80	28	24	5	7	64
	≥ 15	13	7	12		0	32	14	4	1	1	20
	n	35	29	70		16	150	66	76	15	9	166
	m	13.5	12.6	10.9		9.5	11.7	11.1	7.5	8.4	12.1	9.3
	σ	3.9	3.6	4.7		3.7	4.4	4.7	4.7	4.6	2.8	4.9

* Individual Scores Obtained.

'0' Level Results 1973

BAND	REVISED											STANDARD I						STANDARD II				
	SCHOOL											SCHOOL						SCHOOL				
	1	2	3	7	8	10	12	13	14	16	TOTAL	2	8	11	13	16	TOTAL	4	5	10	12	TOTAL
1	6	5	2	3	1	–	–	1	–	1	19	5	2	2	0	0	9	6	0	0	0	6
2	7	4	2	2	–	1	–	1	1	1	19	3	1	0	0	0	4	4	0	0	0	4
3	6	1	6	8	–	–	2	1	1	1	26	2	1	3	3	0	9	3	3	1	0	7
4	8	1	3	5	–	–	–	2	3	0	22	3	3	4	0	0	10	7	2	4	0	13
5	10	0	8	13	1	2	2	1	1	2	40	3	2	1	3	0	9	5	5	2	1	13
6	11	3	6	9	–	4	1	1	10	1	46	4	6	0	2	2	14	6	9	0	1	16
7	8	5	5	8	–	2	1	3	9	4	45	2	2	1	0	1	6	4	3	2	1	10
8	14	3	5	5	1	2	3	3	13	2	51	2	2	17	3	3	27	8	6	1	4	19
9	15	5	10	8	2	1	1	4	11	1	58	3	0	16	4	4	27	7	18	0	1	26
10	7	6	0	6	4	2	1	–	15	1	42	2	6	10	0	1	19	11	7	4	0	22
11	6	4	2	5	4	2	–	–	11	1	35	6	2	11	0	3	22	3	8	4	1	16
12	3	0	3	2	2	2	–	–	7	0	19	0	1	4	0	0	5	4	9	2	0	15
13	7	2	4	2	3	3	–	–	10	1	32	2	3	7	2	1	15	1	4	1	1	7
14	2	0	0	2	1	–	–	–	6	1	12	0	1	1	0	0	2	0	0	2	0	2
TOTAL	110	39	56	78	19	21	11	17	98	17	500	37	32	77	17	15	178	69	74	23	10	176
MEAN	7.1	7.0	6.9	6.8	10.2	8.6	6.5	6.2	9.3	7.2	7.7	6.4	7.6	8.9	7.2	9.0	8.0	6.8	8.7	8.7	8.3	7.9
σ	3.4	3.7	3.2	3.2	3.0	3.2	2.3	2.6	2.8	3.5	3.3	3.8	3.7	2.8	3.1	2.0	3.3	3.4	2.6	3.6	2.3	3.2

Detailed Analysis of Test 5.

No. of correct responses per school

School / Quest.	REVISED							STANDARD I				STANDARD II			
	1*	3	7	8	14	Total	%	8	11	Total	%	4	5	Total	%
1	85	47	64	13	67	276	84.9	18	64	82	82.8	57	43	100	70.4
2	84	45	66	16	70	281	86.5	26	48	74	74.7	36	38	74	52.1
3	73	38	57	11	32	211	64.9	16	21	37	37.4	24	7	31	21.8
4	53	33	47	6	16	155	47.7	11	50	61	61.6	33	36	69	48.6
5	71	39	57	13	48	228	70.2	21	44	65	65.6	35	31	66	46.5
6	65	36	53	11	39	204	62.8	18	48	66	66.7	55	35	90	63.4
7	68	38	52	9	37	204	62.8	16	51	67	67.7	37	33	70	49.3
8	59	36	44	7	29	175	53.8	11	42	53	53.5	40	25	65	45.8
9	9	15	22	4	4	54	16.6	4	9	13	13.1	11	2	13	9.2
10	64	43	56	8	50	221	68.0	16	58	74	74.7	36	43	79	55.6
11	74	48	67	10	53	252	77.5	19	52	71	71.7	33	26	59	41.5
12	77	46	64	10	50	247	76.0	26	50	76	76.8	37	26	63	44.4
13	28	20	28	2	19	97	29.8	6	8	14	14.1	9	3	12	8.5
14	39	25	24	1	9	98	30.2	11	11	22	22.2	18	9	27	19.0
15	85	49	67	15	72	288	88.6	29	61	90	90.9	57	47	104	73.2
16	78	42	58	13	66	257	79.1	28	58	86	86.9	53	59	112	78.9
17	38	22	26	2	29	117	36.0	10	19	29	29.3	27	14	41	28.9
18	50	29	31	8	34	152	46.8	19	31	50	50.5	34	25	59	41.5
19	78	48	58	16	65	265	81.5	19	50	69	69.7	49	49	98	69.0
20	27	18	18	2	12	77	23.7	12	12	24	24.2	17	4	21	14.8
Total No. of Pupils	95	51	70	20	89	325		29	70	99		66	76	142	

* Results of 10 Pupils not included in the analysis.

Detailed Analysis of Test 5.

% Correct Responses

School / Question	Revised					Standard I		Standard II	
	1 (95)	3 (51)	7 (70)	8 (20)	14 (89)	4 (66)	5 (76)	8 (29)	11 (70)
1	89.5	92.2	91.4	65.0	75.3	86.4	56.6	62.1	91.4
2	88.4	88.2	94.3	80.0	78.7	54.5	50.0	89.7	68.6
3	76.8	74.5	81.4	55.0	36.0	36.4	9.2	55.2	30.0
4	55.8	64.7	67.1	30.0	18.0	50.0	47.4	37.9	71.4
5	74.7	76.5	81.4	65.0	53.9	53.0	40.8	72.4	62.9
6	68.4	70.6	75.7	55.0	43.8	83.3	46.1	62.1	68.6
7	71.6	74.5	74.3	45.0	41.6	56.1	43.4	55.2	72.9
8	62.1	70.6	62.9	35.0	32.6	60.6	32.9	37.9	60.0
9	9.5	29.4	31.4	20.0	4.5	16.7	2.6	13.8	12.9
10	67.4	84.3	80.0	40.0	56.2	54.5	56.6	55.2	82.9
11	77.9	94.1	95.7	50.0	59.6	50.0	34.2	65.5	74.3
12	81.1	90.2	91.4	50.0	56.2	56.1	34.2	89.7	71.4
13	29.5	39.2	40.0	10.0	21.3	13.6	3.9	20.7	11.4
14	41.1	49.0	34.3	5.0	10.1	27.3	11.8	37.9	15.7
15	92.4	96.1	95.7	75.0	80.9	86.4	61.8	100.0	87.1
16	82.1	82.4	82.9	65.0	74.2	80.3	77.6	96.6	82.9
17	40.0	43.1	37.1	10.0	32.6	40.9	18.4	34.5	27.1
18	52.6	56.9	44.3	40.0	38.2	51.5	32.9	65.5	44.3
19	82.1	94.1	82.9	80.0	73.0	74.2	64.5	65.5	71.4
20	28.4	35.3	25.7	10.0	13.5	25.8	5.3	41.4	17.1

Detailed analysis of Test 5.

% correct responses - questions in groups.

Group	Question	Revised	Standard I	Standard II
(i)	1 - 3	78.8	65.0	48.1
(ii)	4 - 8	59.5	63.0	50.7
(iii)	9	16.6	13.1	9.2
(iv)	10	68.0	74.7	55.6
(v)	11 - 12	76.8	74.3	43.0
(vi)	13 - 14	30.0	18.2	13.8
(vii)	15	88.6	90.9	73.2
(viii)	16 - 19	60.9	59.1	54.6
(ix)	20	23.7	24.2	14.8

Test Results for School 3.

Pupil	1	2	3	4	5	Total 1 - 5	'0'
1	20	18	17	19	17	91	7
2	19	7	3	3	6	38	9
3	16	16	12	12	17	73	5
4	19	20	16	19	19	93	1
5	20	19	17	19	15	90	6
6	20	18	16	11	16	81	2
7	20	18	15	19	17	91	5
8	20	19	16	19	17	91	2
9	20	19	16	14	17	86	9
10	19	19	17	14	14	83	6
11	18	12	10	6	9	55	9
12	20	8	12	7	10	57	7
13	12	16	7	8	14	57	9
14	18	18	16	13	17	82	5
15	17	18	14	14	17	81	4
16	20	13	9	6	11	59	5
17	19	18	15	12	18	82	7
18	20	10	13	13	17	73	7
19	4	9	13	6	10	42	8
20	20	19	17	19	16	91	4
21	18	20	16	19	17	90	5
22	14	7	4	3	4	32	12
23	20	16	12	20	19	87	3
24	20	18	16	19	16	89	3
25	16	18	14	13	13	74	12
26	18	6	12	10	7	53	11

Test Results for School 3 contd.

Pupil	1	2	3	4	5	Total 1 - 5	'0'
27	20	17	14	10	18	79	9
28	15	12	13	5	9	54	13
29	16	13	13	12	14	68	4
30	19	18	14	11	15	77	9
31	18	16	11	7	13	65	9
32	20	20	16	15	18	89	3
33	20	20	19	19	19	97	1
34	17	19	13	12	19	80	4
35	18	12	13	5	8	56	9
36	19	15	11	11	15	71	7
37	19	9	15	10	15	68	6
38	15	19	15	18	15	82	3
39	19	12	15	6	8	60	8
40	17	17	17	17	16	84	6
41	19	9	17	15	15	75	5
42	18	16	11	8	12	65	8
43	19	17	17	7	13	73	5
44	18	16	16	18	19	87	6

Pupil Questionnaire - Phase II

Research in Chemical Education

Now that you have finished your '0' grade course in Chemistry, we would be grateful if you would read each of the following topics and tick the appropriate column.

No.	Topic	Easy to grasp	Hard to grasp	Never really grasped
1	Structure of the atom			
2	Arrangement of electrons			
3	Formation of ions			
4	Idea of valency (combining power)			
5	Writing formulae like $C\ Cl_4$; SO_2 ; H_2O			
6	Formulae of ions like sulphate, nitrate			
7	Writing formulae like "sodium sulphate"			
8	Calculating formula weights			
9	Calculations involving the "MOLE"			
10	Balancing equations			
11	Calculations from equations			
12	Idea of "MOLAR" solutions			
13	Calculations involving 'molar' solutions			

Questionnaire Responses - 1973

No.	Revised								Standard I				Standard II					Phase I.
	1 (103)	3 (51)	7 (71)	12 (12)	14 (89)	16 (14)	Mean	Mean x 25	11 (70)	16 (16)	Mean	Mean x 25	4 (63)	5 (75)	12 (9)	Mean	Mean x 25	Mean (x 37.5/50)
1	1.233	1.176	1.338	1.000	1.337	1.214	1.265 (.081)	31.7	1.286	1.187	1.268 (.039)	31.7	1.206	1.387	1.111	1.293 (.099)	32.3	26.6
2	1.196	1.157	1.338	1.083	1.360	1.142	1.257 (.091)	31.4	1.300	1.250	1.291 (.020)	32.3	1.111	1.227	1.000	1.163 (.070)	28.1	
3	1.796	1.627	1.704	1.250	1.932	1.500	1.756 (.153)	43.9	1.657	1.875	1.698 (.085)	42.4	1.365	1.892	1.556	1.645 (.256)	41.1	37.4
4	1.223	1.157	1.310	1.500	1.370	1.357	1.285 (.087)	32.1	1.571	1.687	1.593 (.045)	39.8	1.508	1.933	1.333	1.714 (.228)	42.9	31.2
5	1.175	1.118	1.155	1.167	1.360	1.642	1.230 (.124)	30.7	1.371	1.750	1.442 (.148)	36.0	1.254	1.676	1.222	1.467 (.214)	36.7	29.7
6	1.485	1.420	1.563	1.333	1.876	1.928	1.607 (.190)	40.2	1.429	1.750	1.489 (.126)	37.2	1.317	1.893	1.444	1.619 (.283)	40.5	38.3
7	1.243	1.255	1.296	1.167	1.595	1.500	1.356 (.152)	33.9	1.329	1.812	1.419 (.189)	35.5	1.226	1.587	1.333	1.417 (.176)	35.4	34.8
8	1.188	1.216	1.408	1.417	1.370	1.357	1.301 (.096)	32.5	1.414	1.625	1.453 (.083)	36.3	1.371	1.782	1.111	1.565 (.231)	39.1	37.4
9	1.822	1.745	2.085	2.000	2.134	2.071	1.964 (.157)	49.1	2.157	2.500	2.221 (.134)	55.5	2.238	2.308	1.556	2.232 (.177)	55.8	45.2
10	1.490	1.314	1.507	1.750	1.696	1.500	1.531 (.129)	38.3	1.714	1.750	1.721 (.014)	43.0	1.619	2.000	1.333	1.796 (.219)	44.9	41.0
11	1.853	1.686	2.042	1.833	1.932	2.071	1.896 (.116)	47.4	2.157	2.50	2.221 (.134)	55.5	1.825	2.378	1.889	2.111 (.274)	52.8	
12	2.087	1.706	2.197	1.500	2.258	2.142	2.079 (.210)	52.0	2.300	2.25	2.291 (.020)	57.3	2.143	2.253	2.111	2.197 (.058)	54.9	
13	2.126	2.078	2.310	2.333	2.341	2.142	2.221 (.109)	55.5	2.486	2.625	2.512 (.054)	62.8	2.429	2.473	2.222	2.439 (.059)	61.0	

Results of Questionnaire matched with Test 5 Results

Quest. No	Revised		Standard I		Standard II	
	Quest.	Test 5	Quest.	Test 5	Quest.	Test 5
5 (i)	40.4	19.8	45.7	36.7	49.4	51.9
7 (ii)	45.2	39.5	44.3	32.8	47.4	49.3
8 (vii)	43.1	9.5	47.1	12.9	53.1	26.8
9(viii)	65.2	38.4	71.8	43.6	75.8	45.4
10 (v)	50.7	22.4	57.1	27.2	60.8	57.0
11 (ix)	63.0	75.4	71.8	82.9	70.8	85.2

1) For comparisons schools were chosed that had results from both Test 5 and the questionnaire.

Revised: - 1, 3, 7, 14.

Standard I:- 11.

Standard II:- 4, 5.

2) Means from the questionnaire were multiplied by 33.3 to give a mean of 1.5 a score of 50.

3) 5, 7, 8 etc question numbers from the questionnaire (see page A.4.34)

(i), (ii) etc - refer to the grouped data from Test 5 (see page A.4.31).

CHAPTER 5

PHASE 3 - SURVEY OF SITUATION IN 1974

GENERAL CONCLUSIONS, SUGGESTED REVISIONS FOR THE 'O' GRADE SYLLABUS AND SUGGESTIONS FOR FURTHER WORK.

Situation Extant in 1974.

1. In July 1971, the National Curriculum Development Centre for Mathematics and Science published Memorandum No.3 (18) which revised the official position as regards formulae and equations. This document, produced by a joint committee of the Scottish Certificate of Education Examination Board, followed, in general, the same line of argument as has been proposed in this study.

e.g. (i) ".. the reason for writing a formula for such a compound (calcium chloride) is either as a shorthand representation of the substance or as a meaningful unit for calculations. For neither of these purposes is it necessary to indicate its structure. Hence calcium chloride, $CaCl_2$ is to be preferred ....."

(ii) ...it is strongly recommended that ionic charges should not be written in the formulae of such compounds (NaCl, $CaCl_2$).

(iii) "$CaCO_3 \rightarrow CaO + CO_2$ is all that would normally be required rather than $Ca^{2+}CO_3^{2-} \longrightarrow Ca^{2+}O^{2-} + CO_2$.

(iv) "When Zinc is added to a solution of copper(II) sulphate pupils should recognise that the sulphate ion plays no part and the appropriate equation would be

$$Zn + Cu^{2+}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + Cu$$ "

(v) "Where equations are used as a shorthand means of indicating qualitatively what happens as a result of a reaction, or of indicating the main steps, it is unnecessary for them to be balanced. It should be emphasised than even balanced equations need not be written unless they serve a real purpose."

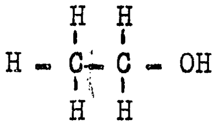
For organic formulae however, it does not go far enough. The recommendation is for "extended molecular formulae" e.g. C_2H_5OH.

When trying to use stage 2 thought processes$^{(6)}$ as far as possible, the more logical conclusion would be to write

CH_3CH_2OH and not C_2H_5OH

As indicated in Chapter 3, this condensation process is best developed very slowly i.e.

first



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & OH \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

secondly CH_3CH_2OH

thirdly C_2H_5OH - only to be recommended because of the possibility of meeting it in the literature.

This document, however, should have continuing repercussions at all levels within the school chemistry scene. It will have made a major advance if the sort of formula and equation writing seen in Chapter 1(p.1.10) as being advocated by some Principal Teachers is laid quietly to rest. However, it raises the problem that the PUPIL is left to decide which is the most appropriate type of formula to use in a given situation and therefore, they must still know the most complex ones. This will possibly mean that some teachers will still always insist on the most complex to stop pupils using 'covalent' type formulae where "ionic" were essential.

2. The inclusion of formulae for oxyanions in the data book issued at S.C.E.E.B. Examinations in and after 1973$^{(21)}$ also was a major step in alleviating the problem of recall as revealed in Phase I (Chapter 2 p. 2.12).

3. The work of I. M. Duncan $^{(22)}$ had shown clearly the difficulties experienced by pupils when dealing with calculations involving the mole, especially those other than 1 : 1 relationships.

Pupils found the concept of concentration in terms of Molar solutions especially difficult and volumetric calculations proved very troublesome. His work does seem to support the belief that the concepts involved are best taught in Class 4, if not Class 5, while confirming the finding of this project that pupils find little difficulty with formula weights, weights of one mole etc.

School 3 also participated in Duncan's programme learning project in May 1973. The results were very encouraging. On his Test 1 - formula weights, mass of 1 mole etc. - which was conceptually undemanding, the mean scores from School 3 on each question were very close to the average for all the schools tested. The pupils in School 3 then, would not appear to be significantly better in overall ability than the rest of the pupils under test. In Tests 2 - 4 however, which measured the more difficult conceptual material such as calculations from equations, molarity and volumetric calculations, School 3 performed considerably better than the other schools under test. This would seem to confirm the high scores of School 3 for these topics in Phase 2 of this present study. This improved performance may of course, be a function of the teacher involved, school conditions, size of class etc., but may also indicate that postponement of these topics, as in the Revised route until Class 4, leads to increased understanding.

4. Publication in 1972(23) of some of the results of Phase I had brought the problems involved in formula writing into the open for public discussion and many teachers expressed agreement with the results indicating their preference for covalently written formulae.

GENERAL CONCLUSIONS

(1) Pupils appear to write formulae mainly by applying learned rules to arrive at the answer without understanding the concepts behind these rules. Some may commit common formulae to memory.

(2) The teaching of formulae and equations using a full ionic approach leads to very poor pupil understanding. In the majority of cases pupils are also unable to translate back from a formulae into words, and state symbols tend only to confuse the issue.

(3) Pupils do not really understand the meaning behind chemical equations and do not appreciate when balancing is necessary.

(4) It is possible to postpone the teaching of ionic formulae, equations, calculations until Class 4 dealing with the "organic" in Class 3 and still present pupils for examination at 'O' grade with at least as much chance of success as following the traditional order.

(5) Teaching formulae and equations from a covalent point of view seems to increase understanding, leading to improved performance in calculations involving formulae and equations.

(6) There is some evidence to suggest that leaving the conceptually more difficult material (mole, calculations etc.) till Class 4 gives improved performance on these topics, while not impairing the performance on the topics studied in Class 3.

(7) There is some evidence to suggest that pupils who were taught from a covalent approach, thought the course easier than those taught from an ionic approach.

(8) The present 'O' grade syllabus (2) contains too much conceptual material at too early a stage for a course that is to serve the top 40% - 50% of the population.

Suggestions For Further Work

1. The work of this study and that of I. M. Duncan(22) and Miss K. D. Urquhart (17) has shown that mathematical problems are often at the heart of failure in certain topics in chemistry. In the experience of the author, pupils often tended to accept overall defeat when faced with the topics that needed mathematical concepts, and in consequence overall chemical performance was adversely affected. Bearing in mind that 'O' grade Chemistry is not directly aimed at producing degree level chemists, an investigation should be made into the desirability of retaining certain mathematical aspects of the present syllabus and to the possibility of delaying material such as molarities, volumetric calculations, proportion calculations, until Class 5. It is proposed(24) to set up in August 1974 in School 3 and one other school in Central Scotland at least three classes containing mathematically less able pupils, to teach them a revised chemistry syllabus in which the mathematical content is of the absolute minimum, leaving out altogether those areas mentioned above, and to present them for examination at 'O' grade in 1976.

2. As this study has found the 'O' grade syllabus to contain too much conceptual material for years 3 and 4 (as did Curriculum Papers No.7 (9) for years 1 and 2,) further investigation should be carried out to consider the possibility of lessening the amount of conceptual material replacing it by lower order skills such as those outlined in Curriculum Papers No.7 (9) e.g. observing, comparing, classifying, (see page 1.06 of this study).

3. These lower order skills are to a large extent dependent on carrying out practical experiments. These of course are ideally done at pupil level. There is the danger, however, that more practical work would mean for many teachers a return to the old style demonstration for the majority of the work. An investigation should be set up to examine what practical work could be included and to find consistent,

reliable and acceptable ways of measuring this at pupil level.

4. There is the possibility that by delaying much of this difficult conceptual material to later in the school course, the pupil who is progressing towards a University course (or courses) in Chemistry, will be adversely affected. He may be inadequately prepared for entry into such a course because of the lack of time in Classes 5 and 6 to include the material that has been delayed from Classes 3 and 4, to sufficient depth.

The solution to this problem would not appear to increase the time allocation for Chemistry in Classes 5 and 6 as this would not be in line with current curriculum development and would tend away from the broad Scottish education to the narrower, more specific English approach.

Rather an investigation should be set up varying e.g. course content, course order, teaching methods, teacher-pupil ratio, to see whether Bruner's now famous maxim that "any subject can be taught effectively in some intellectually honest fashion to any child at any stage of development", can be applied to the study of Chemistry. In effect an investigation to find:-

(i) the best level of treatment of these conceptually difficult topics.

(ii) the correct sequence for teaching by this method of diminishing deception.

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University of Glasgow.

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