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Chemical reactivity: teaching and learning problems and attempted solutions

Bapoo, Abdool Hamid

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1.1.2 B2 Phase 1, (N=411) with teaching undelayed phase 2 (N=138)

1.2 Comparison of standard 8 students results for phase 2 on standard 8 reactivity questionnaire:

1.2.1 C2 Teaching delayed, (old & new schools; (N=357) with teaching undelayed (old & new schools; N=138)

1.2.2 D2 Teaching delayed, (old schools; (N=233) with teaching undelayed (old school; N=54)

1.2.3 E2 Teaching undelayed, (old school; (N=54) with teaching undelayed (new schools; N=84)

1.2.4 F2 Teaching delayed, (old schools; (N=233) with teaching delayed (new schools; N=124)

1.2.5 G2 Teaching undelayed, (new schools; (N=84) with teaching delayed (new schools; N=124)

1.2.6 H2 Comparison of different schools results for phase 2 on the reactivity questionnaire

1.2.7 I2 Comparison of results for schools that took part in both phase 1 & 2 investigations on the reactivity questionnaire

1.2.8 J2 Individual student responses of both the phase 2 delayed and undelayed groups on the standard 8 reactivity questionnaire

1.2.9 K2 Histograms

APPENDICES

PHASE 1

1.1 A1 Standard 8 reactivity multiple-choice type questionnaire

1.2 B1 Standard 10 rate and equilibrium multiple-choice questionnaire

1.3 C1 Standard 8 physical science syllabus (HOD)

1.4 D1 Comparison of standard 8 and 10 results on the reactivity questionnaire

1.5 E1 Comparison of different schools' results for the standard 8 reactivity questionnaire

1.6 F1 Standard 10 results for rate and equilibrium questionnaire

1.7 G1 Comparison of standard 10 students results for the reactivity and rate and equilibrium questionnaires

1.8 H1 Comparison of different schools' results for the rate and equilibrium questionnaire

1.9 I1 Individual student responses to the reactivity and rate and equilibrium questionnaires

1.10 J1 Histograms

PHASE 2

1.1 Comparison of standard 8 students results for phase 1 & 2 on the standard 8 reactivity questionnaire:

1.1.1 A2 Phase 1, (N=411) with teaching delayed phase 2 (N=357)

4.2 Teachers responses during the discussion of the activity cards 155

4.3 Teachers responses to the homework questionnaires 156

5. TEACHING STRATEGY AND METHODOLOGY TO BE USED WHEN TEACHING REACTIVITY 158

5.1 Diagrammatic outline linking key reactivity-related concepts 158

5.2 Teaching strategy for the topic reactivity 168

5.3 Methodology to be used when implementing teaching strategy 170

6. REACTIVITY QUESTIONNAIRE-CONTENT AND GENERAL OUTCOMES 172

7. REACTIVITY QUESTIONNAIRE - ANALYSIS OF RESPONSES 182

7.1 Analysis of the reactivity questionnaire 182

7.2 Review and alternative analysis of the reactivity questionnaire 202

7.3 Analysis of the open ended questions 205

8. SUMMARY OF FINDINGS ABOUT THE INFLUENCE OF THE COURSE FOR TEACHERS ON THE LEARNING BY THEIR STUDENTS 214

9. CONCLUSIONS 222

10. REFERENCES 226

6. SUMMARY OF CONCEPTUAL DIFFICULTIES AND DISCUSSION OF THEIR ORIGIN 114

7. CONCLUSIONS FROM PHASE 1 132

PHASE 2 134

1. MODUS OPERANDI FOR PHASE 2 135
1.1 Designing an "Understanding Reactivity" pack for use in a conceptual change course for teachers 135
1.2 Facilitating a paradigm shift amongst participating teachers 136
1.3 Deliberating about the strategy and methodology for teaching reactivity 137
1.4 Testing the extent to which the course material is transferred successfully to their standard 8 students by the participating teachers of the course 137

2. AIMS AND STRATEGIES OF THE RESEARCH 139
2.1 Objective of research 139
2.2 Research methods 143
2.3 Research design 146

3. OUTLINE OF THE "UNDERSTANDING REACTIVITY" PACK 149

4. EVALUATION OF TEACHERS UNDERSTANDING OF THE CONTENTS OF THE "UNDERSTANDING REACTIVITY" PACK 152
4.1 Teachers ideas about reactivity elicited during pre-course work 152

Chapter	Contents	Page number
1.	INTRODUCTION AND LITERATURE REVIEW	1
	1.1 Misconceptions about rate of reaction and equilibrium	2
	1.2 Misconceptions about reactivity	6
	1.3 Educational theoretical frameworks	10
	1.4 Designing of conceptual change courses guided by the constructivist ideas	14
PHASE 1		18
2.	AIMS AND STRATEGIES OF RESEARCH OF PHASE 1	19
	2.1 Objective of research	19
	2.2 Research methods	22
3.	INTERVIEWS	26
	3.1 Interview responses of standard 8 students	26
	3.2 Discussion of standard 8 interview responses	48
4.	REACTIVITY AND RATE AND EQUILIBRIUM QUESTIONNAIRES STANDARD 8 AND 10 - CONTENTS AND GENERAL OUTCOMES	53
5.	QUESTIONNAIRES	60
	5.1 Analysis of responses to the reactivity questionnaire	60
	5.2 Analysis of responses to the rate and equilibrium questionnaire	82

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completion of the course. Three teachers did not delay the teaching of reactivity to their students.

The outcome of the teaching on the delayed and undelayed groups of students in phase 2 was tested using the reactivity questionnaire. The students whose teaching was delayed performed better than the others. A comparison was also made with the phase 1 standard 8 students. Positive evidence was obtained of the effectiveness of the course.

using the rate and equilibrium questionnaire which incorporated an open ended question on reactivity and reactivity series. Their views were also compared to those of teachers who were the subject of an earlier study.

Standard 8 & 10 students exhibited generally similar misconceptions about aspects related to reactivity. Furthermore the standard 10 students appear to extrapolate their misconceptions about reactivity constructed at a standard 8 level to aspects of rates of reaction and chemical equilibrium studied in standard 10. The students were to a large extent unaware that there is no necessary connection between the rate of a reaction and the equilibrium extent of a reaction.

It appears that teachers, authors of school science textbooks, and curriculum designers are not entirely successful in developing scientifically correct views about rate of reaction and chemical equilibrium with the students.

Phase 2 of the study attempted to address some of the teaching and learning problems associated with the concept reactivity at a standard 8 level. A course was designed for standard 8 science teachers to induce conceptual change as regards reactivity. A key component of the course was an " Understanding Reactivity" pack which was designed guided by constructivist ideas and by the knowledge of misconceptions gained in phase 1.

Seven teachers participated in the course, of whom four delayed their teaching of reactivity to their standard 8 students until the

ABSTRACT

This thesis reports on school teaching and learning problems in the area of chemical reactivity and on an attempt to overcome some of these problems with an in-service course for teachers.

Phase 1 of this research was a study of the conceptions of aspects of reactivity, rates of reaction and chemical equilibrium held by secondary school students.

The nature and origin of the conceptual difficulties, in the above areas were investigated.

The concepts of reactivity and reactivity series are formally introduced at a standard 8 level. These concepts form a springboard for the understanding of more formal quantitative work done in rates of reaction and chemical equilibrium at a standard 10 level.

Two multiple-choice questionnaires, a reactivity questionnaire and a rate and equilibrium questionnaire, were designed to probe for the nature and origin of views held by standard 8 & 10 students respectively.

The views of both the standard 8 & 10 students on aspects of reactivity and reactivity series were investigated using the reactivity questionnaire. The views of a sample of standard 8 students were also probed during interview sessions conducted at selected schools.

Standard 10 students views about concepts related to aspects of rates of reaction and chemical equilibrium, were also investigated

TO MY FAMILY

AND

FRIENDS

I hereby declare that this thesis is my own work. It is being submitted in fulfillment of the requirements for the degree of Doctor of Philosophy in Science at the University of the Witwatersrand, Johannesburg. It has not been submitted to any other University.

Date

28/3/95

Abdool Hamid Bapoo

Bapoo

CHEMICAL REACTIVITY:
TEACHING AND LEARNING PROBLEMS AND
ATTEMPTED SOLUTIONS

By

Abdool Hamid Bapoo

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learning will be limited if implications for teaching and learning are not adopted by teachers.

Millar[66] indicates that rather than proposing a constructivist model of instruction, it might equally well be argued that a consequence of the constructivist model of learning that science should be taught in what ever way is more likely to engage the active involvement of the learner. The constructivist model of learning does not carry any message about models of instruction.

Yager[68] indicates that constructivist teachers of science tend to promote group learning, where two or three groups discuss approaches to a given problem with little or no interference by the teacher. He give an indication of how science teachers can move towards the constructivist approach:

a) seeking out and using student questions and ideas to guide lessons and a whole instructional unit;
b) using student thinking and interest to drive a lesson;
c) seeking out student ideas before presenting teacher ideas or before studying ideas from the textbooks.

Clement et al[67] indicate that appropriate anchoring examples within the learners intuition can assist towards "grounding" instruction. The use of anchors is an example of a more general educational strategy of starting from what the student already knows.

Bodner's[18] summary of the constructivist views stresses that the learner strives to organise information in terms of previous experience. Similarly, Resnick[17] defines learning as an active process occurring as a result of mental construction by the learner.

reactivity? Are they aware that the one has no necessary relation to the other?

2. Do students extrapolate their ideas about reactivity series to the electrochemical series? Do they regard the two series as identical or equivalent?
3. Are students aware that a catalyst influences reaction rates and that it does not affect the equilibrium condition?
4. Are students aware that rate of a reaction is independent of the equilibrium extent of the reaction?

There has to date been no literature reports on student conceptions about reactivity other than Jenkins[26], Moody[25], Markowitz[23] and Meek[24], saying that the notion of reactivity is a difficult one.

1.3 Educational theoretical frameworks

The justification for studying the origins of misconceptions is provided by constructivist learning theories. These attempt to show that knowledge is constructed and also that prior concepts are important for future learning.

Views expressed by various theorists indicate that relevant previous knowledge and experience are important components in the learning process. These ideas pervade the discussion that follows.

Driver & Bell[44] in their summary of the constructivist view of learning emphasize that learning outcomes depend not only on the learning environment but also on the knowledge of the learners who also have the final responsibility for their learning.

Driver[44] also points out that the effectiveness of classroom

ΔG° and ΔH°. Hence approach (ii), related to ΔH°, and approach (iii), related to ΔG°, are unlikely to give the same order, even if they are applied to exactly the same reactions.

Meek[24] also points out that there are many reactivity series but only one electrochemical series. Only voltage measurements of a cell give rise to an electrochemical series. Thus approaches (i), (ii) and (iii) measure different things.

Against the above background it is evident that the concept of reactivity is complex and difficult. It therefore needs to be judiciously handled when formally introduced at the standard 8 level. Are these concepts handled judiciously?

Statements of reactivity concepts, contain everyday terms such as easily, readily, vigorously, readiness and spontaneous. Such vocabulary can generate very different visual images based on personal experience. Teachers attention should be drawn to differences between the technical use of certain words in science and everyday usage of the same terms.

Kleinman et al[45] say that there is also a "common" language problem. Science has its own terminology and language. It is therefore essential for learners to acquire it appropriately. Teaching emphasis should fall on the precise usage of scientific terms.

In the light of the above considerations, the author was led to pose the following questions of a general nature, in formulating this research study:-

1. Are students aware of the different possible meanings of

Meek[24] points out that there are various approaches to the measurement of reactivity:

(i) Visual judgement of the speed of reactions.
(ii) Judgement of the heat of reactions (warm, hot, red-hot, etc).
(iii) Measurement of the voltage of cells.

Students may not be aware of these different approaches for measuring reactivity.
Meek24 points out that in approach (i) the surface areas of the reactants which are in contact affect the speed of the reaction. In school demonstrations, how often are metals equally divided i.e. comparable in surface area?

Approach (ii) should be a measure of ΔH. We should take equivalent proportions of the metal to obtain a measure of ΔH° but in fact few teachers have the time to do this. In practice, speed also comes into the visual judgement: most students will say that the reaction of magnesium powder and oxygen liberates more energy, than the reaction of an equal mass of magnesium ribbon and oxygen. This is probably because the powder reacts more rapidly.

Another type of complication is that the ΔH° of reaction with oxygen per mole of metal and ΔH° of formation of metal oxide per mole of oxygen do not give the same order of the reactivity series.

Approach (iii) is a measure of the free energy of the reaction: $\Delta G^{\circ} = -nFE^{\circ}$. The free energy of the reaction is in turn related to the enthalpy and entropy of the reaction: $\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$. The larger the change in entropy, the larger the difference between

3. Decomposition of metal oxides
4. The displacement of metals from a solution of metal salts
5. Reaction of halogens with metal halides.

Previous authors (such as Jenkins[26]; Moody[25]; Markowitz[23] & Meek[24]) have reviewed the notion of "reactivity series".

Jenkins[26] indicates that the notion is a difficult one, particularly because the term reactivity is capable of both thermodynamic and kinetic interpretation.

Atkinson[62] draws a comparison graphically of the order of the elements in an electrochemical and a reactivity series. He indicates that, in contrast to the electrochemical series, the reactivity series derived from experimental observation takes into account thermodynamic as well as kinetic factors.

Moody[25] says that different reactions give rise to different activity series and also reiterates that the notion of reactivity is a difficult one, because of the ambiguity over the kinetic and thermodynamic interpretation. There is the added difficulty that thermodynamic data cannot, by itself, tell students very much about the actual properties of the materials to which they refer. It is therefore possible to construct a wide variety of reactivity series, depending on the criterion used to measure the so-called reactivity. Markowitz[23] indicates that "the observed reactivity of a material, or violence of a reaction, is often related to the rate at which heat is liberated during chemical combination, rather than to the total amount of heat liberated". Perhaps, the experimental phenomena may be obscuring the meaning of the concept reactivity.

misconceptions about aspects of chemical equilibrium at a standard 10 level. The origin of these misconceptions may however be traced to much earlier schooling. This possibility is the main focus of the present research.

The author attempts to look at the nature and origin of these misconceptions not at the standard 10 level but much earlier, when concepts of reactivity, which are related to rate and equilibrium, are formally introduced at the standard 8 level.

1.2 Misconceptions about reactivity

A study or the Physical Science secondary school syllabus was undertaken to identify topics introduced at an earlier stage that might have relevance to the origins of the confusion students have in differentiating rate from equilibrium. It was hypothesized that in presenting these topics learners had unwittingly been left with an inability to distinguish questions of rate from questions of equilibrium and thermodynamics. The concern was in general students inability to recognise the independence of thermodynamics and kinetics of reaction and also whether students understood that reactivity can be compared from both a kinetic and thermodynamic perspective.

This study of the syllabus led to a focus on the concepts of, *reactivity and reactivity series*. These concepts are formally introduced at a standard 8 level (see Appendix C1 for syllabus) when dealing with the development of the Periodic Table. In the section "Chemical Reactions of Certain Elements" the following are studied:

1. Reaction of metals with oxygen
2. Reaction of metals with water

a) Students failed to distinguish between how fast a reaction proceeds (rate) and how far the reaction goes (extent).
b) Students also believed that, even though equilibrium reactions are reversible, they still go to completion before the reverse reaction commences.

Bapoo, et al[10] also showed that students and teachers had misconceptions about the relation between rate of reaction and chemical equilibrium. The misconceptions are given below.

a) Thermodynamic data was used to make rate predictions.
b) Exothermic reactions are always faster than endothermic reactions.
c) Endothermic reactions cannot be spontaneous reactions.

4. Rate and equilibrium aspects of electrochemistry

Bapoo et al[10] found that amongst a group of teachers and student teachers, that many extracted kinetic information from E° values. Similarly Ogude14 highlighted that students failed to relate measurements of electric current to rate of reaction and measurements of cell emf to the driving force, or the thermodynamic tendency, of the reaction to occur.

On studying the nature of these misconceptions it became evident that many of them were different manifestations of the same primordial misconception i.e. the students lack of understanding that rate and equilibrium are distinctly different concepts which are inherently independent.

Research[1,2,4], has given plausible reasons for the occurrence of

uninformed, equilibrium seems like a quiescent state such as one obtains in the major axis of a spinning top. To the science student however equilibrium should be a dynamic concept.

Equilibrium is fundamental to the understanding of other chemical topics such as acid and base behaviour, oxidation/reduction reactions and solubility. Mastery of the concepts of equilibrium facilitates mastery of these other chemical concepts.

2. Rate of reaction

Hackling and Garnett[3] revealed that the most significant misconception amongst 17 years of age Western Australian chemistry students was that the rate of the forward reaction increases with time, from the mixing of the reactants until equilibrium is established.

In a study in South Africa by Bapoo et al[10] a group of teachers and student teachers were found to have the following misconceptions, to varying degrees:-

a) From a balanced chemical equation the rate law of the reaction was inferred.
b) The rate increased as a function of time - or "as the reaction got going". (a misconception similar to that found by Hackling and Garnett[3])

3. The relation between rate and equilibrium

Wheeler and Kass[13] refer to students inability to distinguish between rate and equilibrium.

1. Equilibrium

Research done by Johnstone et al[14] indicated the nature and origin of conceptual difficulties experienced by students studying chemical equilibrium for the Scottish Certificate in Higher Grade chemistry. Several areas of conceptual difficulties were highlighted by his investigation. Some of these were:-

a) Left and right sidedness.
   Students appear to visualise equilibrium systems as consisting of two independent and separate compartments, rather than as one whole.

b) Interpretation of the reverse arrow convention.
   The longer arrow is interpreted as implying greater rate of reaction at equilibrium.

c) Catalyst.
   i) Catalysts have no effect on the reverse reaction rate.
   ii) Catalysts cause the formation of a higher percentage of products in the equilibrium mixture.
   iii) Catalysts can be used to drive the equilibrium in the desired direction.

Bradley et al[7,10,11] in South Africa studied misconceptions of teachers, related to chemical equilibrium. They pointed out that some teachers had problems with the following:-

a) Distinguishing between closed and open systems.
b) Interpretation of the reverse arrow convention.
c) Interpretation of the effect of temperature on the rate of both the forward and reverse reactions of an equilibrium system.

Buell and Bradley[12] as early as 1972 indicated that to the

regard to the concepts of rates of reaction, chemical equilibrium and reactivity. The need for such a study was indicated by a previous short research by the author[10] on the views of teachers and student teachers. Furthermore it has often been said that senior secondary students in other countries experience difficulty with chemical equilibrium and related concepts.[2,3,4] Chemical equilibrium was rated by a sample of teachers as the most difficult topic for students to comprehend, by Finley et al.[5] Research[2,3,6,9] has shown that chemistry teachers also find this topic difficult.

To provide a background for the research, the following four topics are reviewed in this introductory chapter.

1. Misconceptions about rate of reaction and equilibrium.
2. Misconceptions about reactivity.
3. The educational theoretical framework which has guided this study.
4. Designing courses for conceptual change.

1.1 Misconceptions about rate of reaction and equilibrium

Extensive work has been done on misconceptions, in the various related topics of chemistry listed below.

1. Equilibrium
2. Rate of reaction
3. The relation between equilibrium and rate of reaction
4. Rate and equilibrium concepts related to electrochemistry.

Misconceptions highlighted by research studies in each of these areas are reviewed below.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Many students at all levels struggle to learn chemistry but are unsuccessful. One possible reason for this is that students are not constructing appropriate understanding of chemical concepts early in their studies.

It is said by Nakhleh[1] that the information students use to construct their concepts comes from two sources: public knowledge as presented in text and lectures, and informal knowledge from evidence of everyday experiences. Errors and ambiguities may be found in both these sources and lead to inappropriate understanding.

Similarly, Pines et al[63] discriminate between two sources of individual knowledge of science learning:

1. The knowledge children acquire from their spontaneous interaction with the environment.
2. The knowledge children acquire in a formal fashion through the intervention of the school.

The spontaneously-acquired knowledge is of great importance in its influence on what the child will learn. This first type is his own reality. The second is someone elses reality. Formal knowledge cannot simply be poured in the childs tabula rasa, but rather, formal instruction interacts with a wealth of existing knowledge. It follows that if misunderstandings can be identified, than it may be possible to relate them to errors and ambiguities in the sources of information. If this can be achieved then it may be possible in turn to improve the sources of information in a rational way. This thinking lay behind this research, which was conducted with

1.3 L2 Alternative comparison of phase 2 delayed & undelayed groups on the reactivity questionnaire

1.4 M2 Alternative comparison of phase 2 delayed & undelayed groups with phase 1 group on the reactivity questionnaire

1.5 N2 Alternative and original comparison of the phase 1 group with the phase 2 teaching delayed and un' groups on the reactivity questionnaire

1.6 O2 Understanding Reactivity pack

(H.O.D) were selected. The schools selected were Nirvana Secondary, Lenasia Secondary, M.H.Jusub Secondary, Laudium Secondary, Azadville Secondary and Trinity Secondary. These schools were selected because they were fairly representative with respect to academic standards and with respect to the variety of course options that are offered at Indian schools in the Pretoria, Witwatersrand and Vereeniging regions in South Africa.
The large number of course options offered by these schools implies that the students taking Physical Science do so by choice.

Details of the schools and students used are tabulated.

Dept.	School	Number of Students		
		Std. 8 interviewed	Std. 8 answering std.8 questions	Std. 10 answering std. 8 & 10 questions
H.O.D	1	5 & 5	127	39
H.O.D	2		115	52
H.O.D	3	5	33	32
H.O.D	4	-	48	43
H.O.D	5	-	74	44
H.O.D	6	-	14	25
Total number of students		15	411	235

e) Do students know that the term reactivity may relate, both to the kinetics as well as the thermodynamics of the reaction?

2.2 Research methods

The methods used for analysis purposes by researchers in the field of misconceptions include multiple choice questions, open ended responses and interviews.

The prevalence of misconceptions can be assessed via objective tests (e.g multiple choice) by observing the numbers of students choosing the various options which represent errors or misconceptions. This type of analysis was done by Merrill[27] on some of the National Assessment of Educational Progress (NAEP) science data. This type of test allows for the quick surveying of a large number of students and lends itself very easily to statistical treatment. It has also been widely used by, for example, Helm[28] and Stead and Osborne.[29]

Open ended response tests have also been used extensively, for example by Viennot.[30] In these tests students are supplied with questions which they have to answer in a limited space provided on the question paper. The questions are carefully designed so that students answers give an indication as to how well they understand the concepts concerned.

In the interview approach students may be asked to give explanations for phenomena demonstrated to them. This method has been used by for example Archenhold.[31]

A combination of these methods was used in a complementary manner in this study.

Six schools under the administration of the House of Delegates

reaction?

b) Do students take the strength of an oxidizing agent as an indication of its reaction rate?

c) Are students aware that there is no necessary connection between cell emf (thermodynamics of reaction) and current (rate of reaction)?

3. Catalyst

a) Do students appreciate that a catalyst by taking part in the reaction offers an alternative path of lower activation energy?

b) Do students understand that a catalyst affects the rate of a chemical reaction and not the yield of the products?

c) Do students understand that a non spontaneous reaction cannot be made spontaneous by the addition of a catalyst?

d) Are students aware that a catalyst is a kinetic variable whereas temperature is both a kinetic and a thermodynamic variable?

e) Do students understand that a catalyst does not initiate a reaction?

4. Reactivity & reactivity series

a) Do students understand what is meant by the terms reactivity and reactivity series?

b) Do students understand the meaning of the term spontaneous?

c) Do students take the electrochemical series and the reactivity series to be one and the same series?

d) Do students take the order of the metals in a reactivity series to be invariant?

The understanding of concepts introduced at the standard 8 level was probed with both the standard 8 and 10 students. The standard 8 students were used to reflect approximately the baseline of knowledge achieved by the standard 10 students when they were in standard 8. The understanding of standard 10 concepts by the same standard 10 students was also probed.

This design attempted to shed light on possible links between erroneous conceptions evident at a standard 10 level and the related concepts that are introduced at a standard 8 level.
Furthermore the standard 10 students understanding of standard 10 concepts could be compared to the findings of an earlier study of standard 10 teacher understanding on aspects of rates of reaction and chemical equilibrium.
The specific content-related research questions in the respective topic areas (which are linked to the more general questions posed on page 10) that were probed amongst standard 8 and 10 students during this study, are as follows:

1. *Rate & Equilibrium*

a) Do students appreciate the fact that endothermic reactions can be faster than exothermic reaction?
b) Do students understand that increasing the temperature increases the rate of endothermic and exothermic reactions?
c) Can students differentiate between kinetic and thermodynamic data?

2. *Electrochemical series*

a) Do students take Eo values as indicative of the rate of the

CHAPTER 2: AIMS AND STRATEGIES OF RESEARCH IN PHASE 1

2.1 Objective of Research

The concepts of rates of reaction and chemical equilibrium are implicitly and qualitatively dealt with in the standard 8 Physical Science syllabus. The implicit understanding of these concepts gained in standard 8 forms a springboard for the understanding of the explicit and more quantitative work done in rates of reaction and chemical equilibrium at a standard 10 level.

In view of the above the subjects selected for this study comprised two categories:

1. Standard 8 students doing Physical Science.
2. Standard 10 students doing Physical Science.

The intention was to compare:

1. Standard 8 students understanding of standard 8 concepts with that of standard 10 students.
2. Standard 10 students understanding of standard 8 concepts with their understanding of related standard 10 concepts.
3. Standard 10 students understanding of standard 10 concepts with that of standard 10 teachers as reflected in an earlier study.

In order to obtain the data for the above comparisons, it was decided to:

1. Test standard 8 students on standard 8 concepts.
2. Test standard 10 students on standard 8 concepts.
3. Test standard 10 students on standard 10 concepts.
4. Use test data previously reported for standard 10 teachers in the same or similar schools.

PHASE 1

Summers and Kruger[51] conducted a longitudinal study and found that the teachers did gain a better understanding of force and energy. However they note that the question remains of whether this means they are able to teach these scientific concepts more effectively to children.

Smith and Neale[56] report changes in elementary teachers' understanding of 16 concepts in the area of light and shadows following a four week period of in-service training based on a conceptual approach to the learning of science. They found that teachers' substantive content did change, often dramatically over the training period.

Marton[58] also suggests that conceptual change does not necessarily entail replacement of conceptions because it can also be a process of adding new ideas and learning to distinguish appropriate contexts for their use. Ebenezer and Gaskell[57] found evidence to support this in their study of changes to students' conceptions about solution chemistry.

Lott et al[59] found that teaching teachers to teach for conceptual change was indeed difficult. Nevertheless it is useful to explore the conditions under which students and teachers are prepared to rethink and change their established beliefs and ideas.

During phase 1 of the research that follows, teaching and learning problems on aspects related to chemical reactivity are ascertained and during phase 2 of this research which follows later, solutions for these are attempted.

Summers, Kruger and Palacio[52,53] used a constructivist approach in an attempt to improve primary school teachers' understanding of force and energy. The constructivist pedagogy which underpinned the in-service training of these teachers was informed by the teaching sequence described by Driver[55] and the work of Clement[54]. A four stage approach was used which in summary involved:

-elicitation of existing views
-dissatisfaction with these views
-generation of a better view
-practice and application of new views.

Summers, Kruger and Palacio [52,53] designed packs of teacher education materials to use in their course. The material in the packs makes use of analogies and has been designed to help primary teachers to develop their knowledge of the concepts of energy and force. The packs highlight certain aspects of the scientific view which are known from research to provide particular conceptual difficulties.

Gentner[13] asserts that analogies are of pivotal importance in conceptual change learning in that they may help to restructure existing memory and to prepare it for new information.

Pre-course work forms an important component of the pack as it attempts to make course participants aware of their own understanding before attempting to change them.
Course participants are introduced to the misconceptions which pupils and many adults have and become aware of the nature of their own intuitive views about everyday situations.

attribute of the structure as worthwhile knowledge (discarding some of the internal structure). In other words change takes place within a persons head.

Conceptual change from the phenomenographic perspective is achieved by changing one's relationship with a context. Being able to perceive contexts differently means that one is able to differentiate between them. Changing one's relationship with a specific context means one has changed as a person (see Johannson et al[61]).

Posner[18] outlines conditions under which significant conceptual change is likely to occur: (a) there must be dissatisfaction with existing conceptions; (b) a new conception must be intelligible; (c) a new conception must appear initially plausible.

Schuell[69] points out that science educators also have prior conceptions that can influence their teaching. Thus an adequate understanding of science education must consider the prior knowledge and potential misconceptions held not only by students but also the prior knowledge and potential misconceptions held by science educators.

Vosniadou[70] says that information consistent with the existing conceptual structure can easily be incorporated into the conceptual system. However it is particularly difficult to achieve the kinds of conceptual change that require the revision of ontological and epistemological presuppositions of the framework theory, because they represent a relatively coherent system of explanations.

constructivist view, prior beliefs can also interfere with new learning by causing rejection, or at least a restructuring, of the new material to fit current ideas.[15]

Against this background identifying the origins of misconceptions becomes a priority whilst solutions for their prevention are a logical consequence.

1.4 Designing of conceptual-change courses guided by constructivist ideas.

According to Anderson and Botticelli[41] it is accepted that learning textual information is a complex and dynamic process which involves the mobilisation of existing knowledge, to translate textual information into meaningful units that are integrated into existing memory.

It may be accepted also that creating a cognitive structure of a complex body of knowledge such as chemistry is not easy and that no amount of instruction will help a student who is not determined to work. This research however attempts to remediate some of the misconceptions teachers have about reactivity, which can subsequently lead to a more appropriately structured presentation of reactivity to the students they teach. Better presentations by teachers may lead to better student understanding.

Conceptual change, from the mental model perspective (see Hewson[60]), is achieved by any of the following: acquisition of new information (adding to the internal structure); reorganising existing knowledge (reorganising the internal structure); and no longer viewing some

Stinner[44] quotes Kuhn as saying that textbooks are "pedagogic vehicles for perpetuating of normal science". In the light of the above it is suggested that textbook contents should be organized in a more meaningful way.

Language usage plays a critical role in conveying meaning. One consequence of this is that in teaching our concern should be to help pupils to make their language by building up necessary connections between words[71]. Furthermore they report that:
-the meaning of a word is not absolute but may vary from a general meaning to a more precise meaning;
-understanding of a word depends not only on the context but also the connotation;
-a word in a scientific context is harder to understand than the same word in a non-scientific context.
Veiga et al[73] showed in their studies that misconceptions and difficulties that pupils are known to have were very similar to misleading references used by teachers in their everyday language in the classroom. Teachers have a difficult task since they must talk to pupils in words and language that the pupils understand, but the natural language may contain the very ideas that the teacher is trying to change.

Ribeiro et al[72] show that the influence of meaning from everyday language impacts negatively on the interpretation of chemical phenomena such as reaction and spontaneity.

All these viewpoints stress that knowledge and meaning are actively constructed in the mind of the learner. According to the

Students mastery of new knowledge is believed to depend upon their ability to integrate the new information with existing knowledge.[15-20]

Moreover, it is also asserted that intuitive ("common sense") conceptions resist change, since intuitive ideas are often in direct conflict with the new material.[21] Learners appear to accept selectively those events that support their conceptions while ignoring those observations that are in conflict.

It thus becomes very important that chemistry educators attempt to identify the nature and depth of their students "common sense" ideas.

Ausubel's theory of reception learning[22] places particular emphasis on the students prior learning. One of the more fruitful ways of thinking of how meaningful learning occurs, is in terms of learners constructing their own knowledge. According to this theory it is impossible to teach meaningfully if this baseline of prior knowledge has not been ascertained. In Ausubel's[22] famous words,"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."

Shepardson & Pizzini[42] indicate that the purpose for learning directs the attention to the selection of textual information. Different purposes for learning influence attention differently and thus the selection of textual information. It would appear that the stipulation of objectives at the beginning of a topic or new concept may direct a students attention in a desired direction.

S5: And the ones at the bottom cannot replace the ones at the top.

I: What I am going to do is write an equation on the board. I want to see if you can extract any information from what I have written here.

$Li + O_2 ------>$

$Ca + O_2 ------>$

With reference to the above. Lithium is inserted into a gas jar of oxygen. Now using the reactivity series can you infer what would happen in an experimental set up.

S5: You will get a new substance a different substance.

S4: A compound.

I: You mean that when lithium combines with oxygen you will get lithium oxide.

S4: Yes.

I: So calcium with oxygen you will get?

S5: Calcium oxide.

I: What else can you infer?

S5: The lithium is more reactive than the calcium. So it will take more place.

I: [Repeats.] It will take more place of the oxygen than calcium would.

S1: Ya, you know the electrons it would give it more, whereby it will come more active than Ca with the oxygen.

I: Ok.

S5: This is where speed comes into play. Because lithium is above Ca, it will react faster.

S3: The metals at the bottom can be more easily reduced than the ones at the top.

I: Teacher repeats the above and subsequently asks do you agree with him?

S5: Yes.

I: What does it mean when you say metals at the bottom can be more easily reduced than the metals at the top?

S5: They give electrons easier.

I: Who else wants to comment?

S4: Metals which is first is more active.

S5: Its a stronger reducing agent at the top.

I: And what does that mean?

S5: It has a greater potential to reduce.

I: What does it mean when you say it has a greater potential to reduce. How did you infer that from the experiment?

S1: The teacher told us.

I: You did not do this experiment. Nevertheless writing the following equations on the board:

$$Li + O_2 \longrightarrow$$

$$Na + O_2 \longrightarrow$$

$$K + O_2 \longrightarrow$$

When you say the ones at the bottom are easily reduced, what do you mean by that?

S1: Electrons are lost easier.

I: Do you mean lose faster when you say lose easier?

S1: Yes.

S4: No, metals at the top can replace metals further down.

S3: Copper has the lowest reactivity. Copper is definitely going to be kicked out first.

I: Definitely?

S3: Definitely.

S3: Let me give an example. Lets say copper is 2 zinc 4 and magnesium is 6. In order to make copper to become zero we must subtract 2 in order for zinc to become zero we subtract 4 and in order for magnesium to become zero we subtract. The one that you subtract the least from is the weakest.

I: Subtract 2 what, atoms.

S3: No these are just numbers.

S5: Copper and zinc are both lower than magnesium, magnesium will kick out both metals, you can't really say which one will be kicked out first. The speed I don't really know.

Student responses about the concept reactivity and reactivity series

Group 2

I: Could you perhaps tell me why you arranged the metals the way that you did?

S2: Because reducing agents are at the bottom.

I: Because reducing agents are at the bottom.

S4: The more active metals are at the top and the one's that reacts mostly with oxygen.

I: Lets go back to student number 2. When you say the reducing agent is at the bottom what do you mean by that?

S2: Not sure.

S5: Magnesium has the ability to kick out copper in copper sulphate. It also has the ability to kick out zinc in zinc sulphate. Zinc on the other hand cannot kick out magnesium and therefore magnesium is the most reactive and copper is the least reactive.

I: S4, what have you got to say?

S4: The same.

I: In this case was there a vigorous reaction, S4?

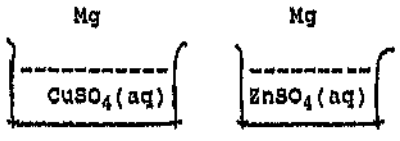
S4: There was no vigorous reaction but there was a reaction.

I: So in terms of what was the relative positions of the metals given?

S4: How many metals they are able to kick out.

[Question reformulated]

I: Lets say for instance magnesium is placed into a solution of copper sulphate and zinc sulphate. What do you predict would happen? [The following diagram is drawn on the chalkboard.



]

S4: Copper is lower in the table so copper will be kicked out first.

S3: That's right.

I: Are you saying magnesium would kick out copper first?

S3: Yes, sir.

I: So are you saying you can tell by using the reactivity series which particular metal ion will be kicked out faster?

S3: Yes, sir.

S4: Yes.

I: Why do you say so?

S4: How reactive they are?

I: What do you mean by that?

[Students: laughing]

Now moving on to a slightly different point.

[Writing again on the chalkboard.

The following table was drawn on the chalkboard to ascertain student conceptions of the reaction of metals with various solutions of metal salts.

	$MgSO_4(aq)$	$CuSO_4(aq)$	$ZnSO_4(aq)$
Magnesium			
zinc			
copper			

The following metals were placed respectively in a solution of three salts as reflected above].

I: I want you to draw a relationship of the reactivity of the metals and give the relative position of the metals.

I: S1, could you perhaps give me the relative position of the metals?

S1: Magnesium is the most reactive then is zinc and copper.

I: Do you go by that, S4?

S4: Yes.

I: Could you perhaps tell me, why did you arrange them the way you did?

S5: It is a series that is arranged from highest reactivity to lowest reactivity err.. from the strongest to the weakest.

I: From the strongest to the weakest. What do you mean by that?

S1: Like sodium is more reactive in water you can see more energy.

S5: From strongest to the weakest.

I: What do you mean S5?

S1. answers

S1: I don't think from strongest to weakest.

I: What do you mean?

S1: I haven't got all my facts straight. Mercury is second last in the reactivity series and from what I learnt it is really powerful.

I: Powerful.

S1: No, not powerful, its .....

I: What do you mean when you say its powerful. Do you mean fast?

S1: No not fast, no not from any experiments, from book knowledge. So I think its just how it reacts, whether it is a weak reaction or like a low reaction or its high compared to another reaction.

I: What do you mean by low reaction or high reaction?

S1: Like with sodium when you see it in the water it moves like fast. You see like it has more zest in it. Like with lithium it moves as well but not so fast or not with the same speed. It's like a slow kind of a reaction it is not as energetic.

I: If you have a class of students. What would you tell them a reactivity series is. It is the relative positions of the metals in terms of?

S1: Yes, sometime the two metals forming together can form something dangerous substance.

S3: Something dangerous can happen.

I: What did you mean when you said the reaction is faster?

S4: I would not say the reaction, the movement, the way it moved across the water.

I: Which reaction gave hydrogen faster. When lithium reacted with water or when sodium reacted with water?

S4: When sodium reacted with water.

I: So does reactivity mean how fast sodium reacted with water?

[I: At this stage a few other reactions pertaining to the reaction of metals with water are written on the board.

Sodium + water ---------->

magnesium + water ------->

zinc + water ------------>]

I: Using the reactivity series which metal would you say reacts the fastest with water?

S4: Sodium, but only according to the reactivity series.

I: From this reactivity series can you say that sodium would react the fastest with water?

S3: Yes, I would say so. If you throw magnesium in the water it takes long to react but with sodium it will react immediately.

S4: Yes, sodium is stronger than magnesium.

I: What do you mean stronger?

S1: You cannot say stronger if you do not know what the metals are made up of.

I: Essentially, then what is a reactivity series?

S1: It is probably because of what type of flame it was.

I: So, what does the term reactivity mean to you?

S4: It is so much better if we know what the term means, we cannot say what the term means and therefore cannot say what the metals are made off and therefore cannot say why they react the way that they do.

[I: At this stage the following reactions are written on the chalkboard.

Sodium + water ---------> sodium hydroxide + hydrogen

Lithium + water ---------> lithium hydroxide + hydrogen]

I: Using the reactivity series, which metal would you say is more reactive?, S4.

S4: Sodium.

I: Why do you say that sodium is more reactive?

S3: Sir according to what we saw, the reaction was more vigorous.

I: So you would say because the reaction was more vigorous, it was more reactive. So what do you mean when you say that the reaction is more vigorous. Do you mean that the reaction is more faster?

S1: The reaction took place faster. The way it darted across the surface it was fast. You could see that there was friction on the water.

I: S1, if you are saying that the reaction is faster, should you not know the chemical equation for the reaction?

S1: Yes.

I: Why?

Group 1

I: With reference to the experiments on the reaction of metals with oxygen that have been demonstrated, I want you to jot down everything you have observed and thereafter you can deduce anything from the observations.

I: Did you deduce any relationship between the metals, S1?

S1: Most of the metals reacted except for calcium and copper there was no visible reaction.

I: What is the order of your reactivity then?

S1: Na, Li, Mg and Zn.

I: Why did you arrange the metals in the way that you did?

S1: You arrange them that way so that the most reactive is at the top and the least reactive is at the bottom.

I: How did you ascertain that one metal is more reactive than the other metal?

S1: From the flame.

I: So are you saying the brighter the flame the more reactive the metal?

S2: No, not necessarily it depends on how quick it makes.

I: You mean how fast.

S2: The speed with which it ignites.

I: S3, what do you say, can you account for the order?

S3: The flames were quite bright and strong and vigorous.

I: You mean the flames were not too violent with zinc and oxygen.

S3: Yes, with sodium the flames were most violent.

I: So what are we saying here, that you have extracted the relative positions of the metals on the basis of what?, S1.

CHAPTER 3: INTERVIEWS

The interviews were used as a component of the research study to elicit free verbal response.

These interviews were conducted approximately two days after the following experiments were demonstrated by their teachers. Students that were interviewed were allowed to refer to the worksheet that they had used during their experiments.

1. the reaction of metals with oxygen.
2. the reaction of metals with water.
3. the reaction of metals with solutions of metal salts.

The students responses helped to illustrate student understanding of the following terms:

- Reactivity and reactivity series
- Spontaneous reaction
- Catalyst
- Exothermic and endothermic reaction.

Students were afforded the opportunity to verbalise their understanding so that any misunderstanding could be identified.

In the following dialogues, response by student number n is indicated by "Sn" and the interviewers comments are marked by "I". Furthermore descriptions which were not part of the dialogue are placed between square brackets.

3.1 Interview responses of standard 8 students

Student responses about the concept reactivity and reactivity series.

This questionnaire was done first by the standard 10 students to obviate students using multiple-choice options from the reactivity questionnaire to answer some of the questions in the rate and equilibrium questionnaire.

The reactivity questionnaire was administered simultaneously to both standard 8 and 10 students doing Physical Science on the higher grade. It was administered approximately a month after the rate and equilibrium questionnaire had been written. At this stage standard 8 students had received instruction on reactivity and reactivity series. Standard 10 students had of course received instruction, two years previously.

The head of department (H.O.D) of Natural Science in each school was contacted, after permission was given by the principals (acting principals) of the respective schools. Firstly the rate and equilibrium questionnaires were delivered to the H.O.D of Natural Science who was requested to handle the distribution and collection of the standard 10 questionnaires after the standard 10 students had completed them.

The H.O.D. was requested to tell the teachers who were invigilating that the duration of the test was about 30 minutes and that this was a survey in chemical education.

The questionnaire was written simultaneously by all the pupils in a particular school.
Similar procedures were adopted by the other schools that were used for the survey.

1. Interviews

For the interviews five students per standard 8 class in two different schools were selected. In one school two groups of students were interviewed. Two students were selected from the upper, two from the middle and one from the lower groupings, in terms of the marks obtained for Physical Science in the standard. Each interview was tape-recorded with the permission of the students. The duration of each interview was approximately 1.5 hrs. These interviews were conducted at least two months prior to the answering of the reactivity questionnaire.
The interviews gave much insight as regards the type of questions to be incorporated in the questionnaires.

2. Questionnaires

Two separate reactivity and rate and equilibrium multiple-choice type questionnaires of thirty minutes each, were designed.
One questionnaire contained only multiple choice questions, and the other multiple choice questions and open ended questions. They both aimed to probe misconceptions of students at a standard 8 and 10 level respectively, in aspects of rates of reaction and chemical equilibrium.

First, the rate and equilibrium questionnaire was administered to standard 10 students, doing Physical Science on higher grade. The questionnaire was administered after the students had received instruction in rates of reaction, chemical equilibrium and electrochemistry.

S1: It helped the ...it speeded the combining in the making of lithium oxide.

I: That is interesting. What is a catalyst. You mean light can be a catalyst?

S1: Yes.

I: Can heat be a catalyst?

S1: Yes it could be because it speeds up the reaction with lithium and oxygen.

Student responses about the concept endothermic and exothermic reaction.

Group 3

I: What is an exothermic reaction?

S2: When heat is released.

I: When heat is released, so exothermic reaction is a reaction when heat is released.

S2: When heat is given off during a reaction.

I: When heat is released or energy is released?

S1: Heat is energy. [Laughing.]

I: What if a reaction releases sound energy?

[Students: Laughing].

I: Look at the reaction of lithium with oxygen. Is this reaction exothermic or endothermic?

S3: Exothermic.

I: Why?

S1: Because we heated the Li.

I: But 2 Li +1/2 O_2------> Li_2O + heat

S1: .....I'm confused.

Student responses about the concept endothermic and exothermic reaction.

(group 1 was not interviewed on these aspects due to lack of time.)

Group 2

I: Are you aware of the term endothermic?

S1: Yes.

I: What does the term endothermic mean?

S1: ...something that takes up heat. I think so. An exothermic gives off heat.

I: Ok.

S3: Like for lithium and oxygen to combine, you must need heat, so its exothermic. So you call it exothermic reaction.

I: Because light is given off.

S3: Because heat is needed for the compound to react.

I: Lets take this reaction on the board.

$$2\ Li + 1/2\ O_2 \text{------->}\ Li_2O + light$$

Is this reaction exothermic or endothermic?

S1: Endothermic.

I: Because we used heat.

I: But when the product was formed heat was given off.

S1: Then its exothermic.

(Students: All laugh)

I: Is it exothermic or endothermic?

S1: No, no the heat was a catalyst.

I: The heat was a catalyst. Why do you say so?

S3: Speeds up the reaction but does not alter the chemical substance.

I: Li was inserted into a gas jar of oxygen. But Li had to be heated before it could react. So what do you think was the function of the heat?

S1: It was used as a catalyst because it speeded up the reaction.

I: Would you go by that?

Students: Yes.

I: However earlier you said that it speeds up the rate of the reaction but does not change the chemical substance. Did you not say something to that effect?

[Students/interviewer Laughing].

S1: When we used $KClO_3$ to prepare oxygen.

I: Right.

S1: We used a catalyst, it speeded up the reaction.

I: Now in the case where Li had to be heated, would you say heat is a catalyst?

[Students: Hesitant.]

I: Another question. A catalyst you say speeds up a reaction. In the decomposition of potassium chlorate, you get oxygen given off and you get potassium chloride. What does a catalyst do to the amount of oxygen? Do you get more oxygen?

[Students: Silent.]

I: Reformulating. Does a catalyst affect the yield of the products?

Students: No!

S1: No, no, just speeds up the reaction.

S4: Not necessary speed up. Sometime it can even decrease.

I: How does it change the speed if it does not take part?

S3: It remains what it is like manganese dioxide.

S1: It does not mix with the reaction.

Student response about the concept catalyst.

Group 2

I: Did you hear the term catalyst before?

S4: Yes.

I: What does the word mean to you?

S4: Something that speeds up the reaction between two things.

I: The rate of the reaction?

S4: Yes the rate of the reaction.

I: Between two things what do you mean?

S1: or.....

Student responses about the concept catalyst.

Group 3

S1: A catalyst is something that is added to another substance to speed up without taking part in the reaction.

I: Would you go by that? Could you perhaps tell me how does it speed up the reaction if it does not take part in the reaction?

S2: It speeds it up it does not undergo any change.

I: What do you mean if you say it does not undergo any change? What type of a change? Change with respect to what.... colour, shape etc. What do you mean?

S1: Yes.

I: We're saying a spontaneous reaction is a reaction that is fast. A slow reaction cannot be spontaneous.

S2: Spontaneous reaction can also be like no heat is applied.

I: So if you do not apply any heat and it reacts then it is a spontaneous reaction.

S2: Yes ,that is what I am saying.

I: And if you apply heat to it then it is not a spontaneous reaction.

[Students: Laughing].

I: You were saying something.

S1: If you combine two substances the reaction is almost immediate. So its spontaneous it does not take long for it to react.

I: So if it takes long for two substances to react then it is not spontaneous?

S1: No

I: Is that so?

S1: Yes.

I: So that means it must react quickly, for it to be spontaneous?

Student responses about the concept catalyst.

Group 1

I: What is a catalyst, S3?

S3: Speed up a reaction but does not undergo a change or take part in the reaction.

I: It is used to speed up the reaction without taking part in the reaction.

Student responses about the concept spontaneous reaction.

Group 2

I: Did you hear the word spontaneous?

Students: yes.

I: Could you explain what the term means?

S4: Something that happens over and over again.

I: Over and over.

S3: Something that happens on the spur of the moment. It just happens.

S1: I don't think that the reaction can take its own sweet time.

I: Yes, but what does the term spontaneous mean?

S1: When two elements combine without the use of a catalyst.

I: Of the what?

S1: Of the catalyst.

I: Spontaneous reac in a reaction that takes place without the use of a catalyst?

S1: Yes.

Student responses about the concept spontaneous reaction.

Group 3

I: What does the term spontaneous mean? Does it mean the reaction has to be fast?

S1: Yes reaction takes place almost immediately.

I: So a spontaneous reaction is a reaction that takes place immediately.

I: Which is more reactive Zn or Mg?

S1: Mg

I: Looking at the relative positions of Zn and Mg in your reactivity series, since they are reacting with the same substance. So can you infer anything from the reactivity series?

[Students: ....silence].

I: Can you say in which beaker will Cu be deposited first?

S1: Second, copper would be deposited first.

I: Do you go by that. Do you think you can extract this from your reactivity series?

Students: Yes

Student responses about the concept spontaneous reaction.

Group 1

I: S4, you were saying the reaction was very spontaneous. What did you mean by that?

S4: What I meant is that a few of them did not ignite spontaneously. It took a long time before it ignited.

I: So what does the term spontaneous reaction mean to you?

S4: Fast.

S3: You put it on top of a flame ignites straight away. Some chemicals, you have to wait for a while to get it flamed.

I: S1, what does spontaneous mean to you?

S1: It carries on it is on going.

I: It is on going.....You mean it can be slow?

S1: The process is on going it does not go off.

S1: The reaction between lithium and oxygen is faster than between Ca and oxygen.

I: Lithium and oxygen will be quicker than between Ca and oxygen.

S2: Lithium is more reactive than Ca.

I: So your reactivity series is actually a series that tells you what?

S1: How fast the elements react with substances when they combine.

I: Would you people go by that? Ok, what I am going to do now is go onto the other experiment. The reaction of metals with solutions of metal salts.

Now in relation to what you have said, I have two equations on the board..

[1) $Zn + CuSO_4 \text{------>} ZnSO_4 + Mg$

2) $Mg + CuSO_4 \text{------>} MgSO_4 + Cu$]

I: Now in terms of your reactivity series, which is more reactive Mg or Zn?

S1: Mg.

I: OK, Now if Mg is more reactive than Zn. Now could you tell me in terms of the reaction written above what can you infer from using the reactivity series?

S2: The weaker one gets displaced by the stronger one. Zn is stronger than Cu so Zn displaces Cu.

I: Ok, and in the second case?

S1: Mg is stronger than Cu and Cu is displaced by Mg.

I: What else can you infer?

S1: $ZnSO_4$ and $MgSO_4$ is formed.

Group 3

I: Could you account for the arrangement of the metals when the metals reacted with oxygen?

S1: Potassium first because it was most reactive with oxygen, then sodium and then lithium.

S2: The alkalis metals were first.

I: How did you ascertain which is more reactive? Think out aloud. Don't be scared. I want to try an ascertain what is happening inside your mind.

S2: It burn more vigorously.

I: You say its more vigorous; lets get back to your question. What are you implying when you say its more vigorous?

S1: That it is more reactive.

I: What does that mean vigorous in terms of what?

S1: When potassium is inserted into a gas jar, the reaction is almost immediate, spontaneous.

I: The reaction was spontaneous.

S1: The reaction was almost immediate.

I: Right.

S1: Sodium followed potassium, magnesium followed calcium. You ' rot heated potassium, it caught alight almost immediately

[The reactivity series is given.

K,Na,Li,Ca, Mg.]

I: Using your reactivity series what can you infer if lithium is inserted in a gas jar of oxygen and when calcium is inserted in a gas jar of oxygen?

S4: I think that Mg will take the place of Pb. The pieces of metals will float at the top.

I: Is that all you can infer? That means Pb will be deposited in both beakers?

I: Yes. Looking at the relative positions. You can see where Mg is and where zinc is. What other aspect can you infer?

S4: Mg and Zn are more active elemants than Pb, because they on top and take place of the less active.

I: Which is most reactive, Mg or Zn?

S1: Mg it is higher up.

I: Ok, what does that mean?

S1: Mg is a stronger reducing agent and Zn is a stronger oxidizing agent.

I: And what does that mean?

S1: The Mg would undergo oxidation. The Mg loses more electrons.

I: More electrons?

S1: Mg gave more electrons.

I: In which beaker would metals be deposited faster?

S3: In the Mg beaker.

I: Why?

S1: Because Mg is higher up in the series.

S1: Mg lose electrons faster than Zn.

I: Do you agree?

S3: Yes.... they lose relatively.

Student responses about the concept reactivity and reactivity series.

S5: How fast something can be done.

I: Now, what is being formed here?

S5: Lithium oxide.

I: So you are looking at the rate the lithium oxide is formed compared to calcium.

I: Ok, in order to know the rate at which lithium oxide is going to be formed, should you not know the equation?

S5: Yes... that sounds better.

S4: Yes, to show how many types.

I: Is it important to know how to balance the equation. Are you saying that you cannot measure the rate without knowing the equation?

S3: I think to an extent it plays an important part to know the time taken for the reactions to form.

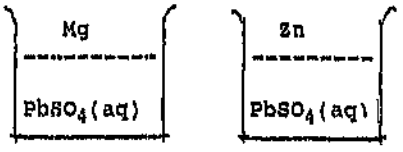
I: Would the reactions be important if you are trying to infer what the rate would be?

S4: Yes, because usually you also use the halfway sums.....

I: I am going to the displacement of metal ions in a solution of their salts

[The following series is written down

Mg, Zn, Fe, Pb,Cu



]

I: Using the series can you infer anything that would probably happen?

I: React faster with what?

S5: Faster with oxygen.

I: You think so. What are you implying by that? Are you saying lithium oxide is formed faster than calcium oxide? Is that what you can infer from the series?

S3,4 & 5: Yes.

I: Are you perhaps saying that lithium has a greater tendency to combine with oxygen than Ca would?

[Students: Laughing.]

I: Why are you laughing?

Students: Confused now.

I: Assume you are talking of speed, is the amount important?

S4: Ya, the greater the oxygen is, and the greater the lithium. The more there is the longer it will take.

I: The longer it will take.

S4: Yes, in terms of speed.

I: Are we talking about speed?

S5: It might take the same amount of time if we put a little more oxygen in the second jar where calcium is.

I: You are saying if we have more it will take a longer time. You are saying the speed would be less?

S5: Yes, the speed would be less.

I: What do you mean when you talk of speed? How would you define speed?

S1: How long it will take.....to to form a new compound.

I: A new compound like lithium oxide. Right so if you measure rate what does the term mean?

7. Histograms. (Appendix J1)

- Histogram showing a comparison between standard 8 and 10 students responses to the reactivity questionnaire is given.
- Histogram showing the standard 10 student responses to the rate and equilibrium questionnaire.

The responses to each questionnaire are dealt with in more detail in the next chapter.

4. Comparison of standard 10 students' results for the reactivity and rate and equilibrium questionnaires.(Appendix G1)

A Students t-test was employed on the scores of 82 individual students out of the 235 that wrote both the standard 8 and the standard 10 questionnaire. The students' average marks for the respective questionnaires were compared. The t-test indicates that the average mark obtained by the 82 students for the respective questionnaires does not differ significantly at $\alpha = 0.05$.

A small, negative, non-significant correlation coefficient (Pearson's rho= -0.12529) was calculated for the marks of individuals on the two questionnaires. This indicates the absence of a relationship between the marks of individuals on the respective questionnaires.

5. Comparison of different schools results for the rate and equilibrium questionnaire. (Appendix H1)

The performance of the standard 10 students of each school for the standard 10 questionnaire is given. Each school obtained on an average 22%-25%. The schools results amongst themselves were not significantly different at the 5% significance level.

6. Individual student responses to the reactivity and rate and equilibrium questionnaires. (Appendix I1)

The total mark obtained for the respective questionnaires by each student is given.

questionnaire.

The following null hypothesis H_0 and alternate hypothesis H_1 are assumed.

H_0: The mean responses for standard 8 and 10 are equal. ($\mu_8 = \mu_{10}$.)

H_1: The mean responses for standard 8 and 10 are not equal.

(i.e $\mu_8 \neq \mu_{10}$)

(The level of significance is taken to be $\alpha = 0.05$ or the 5% significance level)

The probability of getting a t-value as large as 2.3035 if H_0 is true is 0.0216. Therefore H_0 is rejected and we conclude there is a significant difference between the mean of standard 8(μ_8) and the mean of standard 10(μ_{10}) at $\alpha = 0.05$. (std.8 mean = 24%, std.10 mean = 21%).

2. Comparison of different schools' results for the reactivity questionnaire (Appendix E1)

The performance of the standard 8 students of each school for the standard 8 questionnaire is given. The average performance at all the schools was poor. School number 5 (35%) did significantly better than the 5 other schools, but the other schools did not differ significantly amongst themselves. (19%, 23%, 17%, 23%, 23%)

3. Standard 10 results for the rate and equilibrium questionnaire (Appendix F1)

The overall results on the rate and equilibrium questionnaire by the standard 10 students include the mean percentages for the correct response for each question. They fall between 5.5% and 33.6%.

correct/wrong ratio is the same irrespective of standard.)

The following null hypothesis H_0 and alternate hypothesis H_1 are assumed.

H_0: The response is independent of standard.
H_1: The response is not independent of standard.
(The level of significance is taken to be $\alpha = 0.05$ or the 5% significance level.)

For question 1 the probability of getting a valte of X^2 as large as calculated is 0.730. Since Probability > 0.05, H_0 is not rejected and we conclude that the standards are not different in their responses at $\alpha = 0.05$.
A similar conclusion holds also for questions 4,5,6 and 7.

For question 2, the probability of getting a value of X^2 as large as calculated is 0.037.
Since Probability < 0.05, H_0 is rejected and we conclude that the standards are different in their responses for this question.
A similar conclusion holds for questions 3 and 8. In all questions (2,3 and 8) where there is a significant difference, standard 8 students performed better than standard 10 students.

A Students t-test was employed to compare the overall average obtained by the 411 standard 8 students for the standard 8 questionnaire with that of the 235 standard 10 students for the same

3. Standard 10 results for the rate and equilibrium questionnaire. (Appendix F1)
4. Comparison of standard 10 students results for the reactivity and rate and equilibrium questionnaires. (Appendix G1)
5. Comparison of different schools results for the rate and equilibrium questionnaire. (Appendix H1)
6. Individual student responses to the reactivity and rate and equilibrium questionnaires. (Appendix I1)
7. Histograms. (Appendix J1)

1. Comparison of the standard 8 and 10 results on the reactivity questionnaire (Appendix D1)

This questionnaire was written by 411 standard 8 and 235 standard 10 students from 6 different schools.
The average percent choices by these students for the correct responses and the accompanying options for each question of the reactivity questionnaire are given.

For the purposes of the comparison the responses for the multiple-choice questions were treated as either 0(wrong) or 1(correct) i.e the resulting data is not normally distributed. A X^2 test was then employed to compare the results of standard 8 students to those of standard 10 students for the standard 8 reactivity questionnaire.
A Chi squared test for independence was carried out to determine whether or not the correct/wrong response is independent of whether students are standard 8 or standard 10 (i.e whether the

Concept	*Rate*	*Equilibrium*
spontaneous reaction	-	equilibrium
catalyst	rate	-
E°	-	equilibrium
ΔH°	-	equilibrium
strength of oxidising agent	-	equilibrium
reactivity	rate	equilibrium
reactivity series	rate	equilibrium
electrochemical series	-	equilibrium

In an earlier "pilot study" by Bapoo, et al[8], questions related to the above concepts were also incorporated. Some of the questions designed in that study were used unchanged in this study. Others were used in partially altered form.

Results

The results of the following analyses are given in the appendices as shown below.

1. Comparison of the standard 8 and 10 results on the standard 8 reactivity questionnaire. (Appendix D1)
2. Comparison of different schools results for the standard 8 reactivity questionnaire. (Appendix E1)

CHAPTER 4: REACTIVITY AND RATE AND EQUILIBRIUM QUESTIONNAIRES

STANDARD 8 AND 10 - CONTENTS AND GENERAL OUTCOMES

The reactivity questionnaire was designed to ascertain students understanding of the concepts reactivity, reactivity series and related concepts tested earlier in the interviews. The distractors used for the questions, referred to possible misconceptions. The contents tested by the questions were concepts within the framework of the topics rates of reaction and chemical equilibrium.
The distractors for the questions on reactivity series had a "rate bias", i.e. they invoked a connection between rate of reaction and reactivity. Hardly any distractors were related to the overall energetics (equilibrium) of the reaction. Options such as "none of the above" were included so that, if students felt that the options which were given did not relate to either the kinetic or the thermodynamic implications in the term reactivity, they could choose these options.

The rate and equilibrium questionnaire was designed to test whether students could distinguish between rates of reaction and chemical equilibrium.
Distractors were related to both the rate and chemical equilibrium aspects of reactions. The questionnaire aimed to test whether the specific concepts given below were interpreted in a kinetic or a thermodynamic sense. The correct association of the specific concept with the general concept of "rate" or "equilibrium", is given below.

G2, S1 (No, no ...) to S1 (Yes, it could...)].

Statements (1) & (2) give the notion that students are aware that a catalyst increases the rate of the reaction, but they also clearly do not know how a catalyst works.

Exothermic and endothermic reaction.

Students could not differentiate between two distinct processes i.e. the initial heating of lithium and the subsequent reaction of lithium with oxygen which is an exothermic process. Whether the overall reaction of lithium with oxygen was exothermic or not was not clear.

Lithium was heated before a reaction took place and the reaction of lithium with oxygen was therefore considered to be endothermic. Students therefore could not distinguish activation energy (a kinetic concept) from the endothermic nature of some reactions (a thermodynamic concept). [p 48, G3, I (What is ...) to S1 (You making ...)].

Students did not suggest that a thermometer is an instrument that is an extension of their sense of touch and that it could be used to indicate whether a reaction is exothermic or endothermic.

2. The reaction takes place without any time delay and is immediate.
   [p 41, G1, S3 (You put ...) to S3 (You put...)]; [p 42, G2, S3 (Something ...) to S1 (I don't...)]; [pp 42,43, G3, S1 (Yes ...) to S1 (Yes...)] & [p 43, G3, S1 (If you ...) to S1 (Yes...)].

3. A spontaneous reaction does not require a catalyst.
   [p 42, G2, I (Yes ...) to S1 (Yes...)].

4. A spontaneous reaction takes place without heating.
   [p 43, G3, S2 (Spontaneous...) to S2 (Yes...)].

Statements (1),(2) & (3) link the term spontaneous to speed, and speed is implicitly linked to "time". Students appear to be linking the concept of spontaneity to time, which falls in the province of kinetics.

Statement(4) may be linking the concept with thermodynamics, perhaps implying that an endothermic reaction is non spontaneous. However this too may be kinetic - ie implying a low activation energy.

Catalyst

Two important points of view illustrated by the interview statements are:

1. A catalyst speeds the rate of the reaction *without taking part in the reaction.*(my italics)
   [p 43, G1, I (What is ...) to S3 (Speed up...)]. [p 44, G3, S1 (A catalyst ...) to S1 (A catalyst...)].

2. The application of "heat" to lithium when reacting with oxygen was considered by some as a catalyst.
   [p 45, G3, I (Li was inserted ...) to Ss (Yes...)]. [pp 46,47,

The general description of reactivity series was simply as a series reflecting how reactive a metal is, without understanding what the term reactivity meant. Many responses exposed lack of clarity and a sense of uncertainty regarding the concept reactivity. Terms like spontaneous, vigorous, strong and weak were used to explain the concept of reactivity, without any specific scientific meaning of the terms. They seem to be used rather like alchemists might have used them - almost anthropomorphic or animist. [p 28, G1, S1(It is probably the...) to S4(It is so much ...)].

A reactivity series was considered by some students not to be a general concept, but specifically linked with reduction.
One student also gave the metals in the series arbitrary values, thus indicating perhaps that it was seen as analogous to an electrochemical series. In school textbooks the electrochemical series is the only "reactivity series" which is associated with numerical values.

No students referred to equilibrium or extent or direction of reaction in talking about reactivity and reactivity series.

Spontaneous reaction.

The following aspects pertaining to the students understanding of the term spontaneous reaction were highlighted in the interviews:

1. A spontaneous reaction is fast. [p 41, G1, I (So what ...) to S4 (Fast...)].

Reactivity and reactivity series

Interviewed students often described a reactivity series as a series reflecting the relative speed of the reactions.[p 27 G1, I(So are you..) to S3(Yes)];[p 40, G3, S1(The reaction...) to S1 (How fast...)]

The more reactive metal in the displacement of a metal from a solution of its salt was considered to displace the metal faster than a less reactive metal.

Students tended to judge all these reactions by speed (kinetics)i.e the rate at which metals are deposited or the speed with which metals are "kicked out". [pp 32,33, G1, I(Lets...) to S3 (definitely)]; [pp 38, G2, I(Yes.) to S3(Yes.)] & [p 40, G3, S1 (The reaction...) to S1(How fast...)]

Though students viewed the reactivity in terms of rate they felt that if the amounts of reactants increased, the reaction would take longer and consequently the rate of the reaction would decrease. Ideas of reaction rate are not at all clear. [pp 33,34, G2, I(Could you ...) to S1(Teacher told ...)] & [p 36, G2, I(Assume ...) to S1(How long...)]

The rate view of reactivity which was earlier adopted when describing metals reacting with oxygen, seemed to be tacitly transferred to the reaction of metals with solutions of various metal salts.

The total quantity of heat evolved during the reaction - a thermodynamic characteristic - seemed to be neglected.

I: What is an endothermic reaction?

S1: A reaction that absorbs heat during a reaction.

I: Sometimes you supply heat to reactants, but when the reaction is started energy is given off. So do you mean that when heat is required for a reaction to take place it is endothermic. Or must the overall reaction be accompanied by the absorption of heat?

S1: You making me think.

S2: Endothermic.

S1: But heat was given off, therefore it is exothermic .

I: Ok, can a catalyst speed up an endothermic reaction?

Students: silence.

I: Ok. Lets move on. How do you know when heat is given off in an exothermic reaction? Do you have to see light in an exothermic reaction? How do you recognise an endothermic reaction? How would you test for it?

S1: If you feel the heat, then it is exothermic.

3.2 Discussion of standard 8 interview responses.

In the following discussion links between transcript statements and analysis claims are given in the format [page number, group of students, student no.(starting statement) to student no.(ending statement]. An example of the short notation would be [p30, G1, I(From the...) to S1(No, not powerful...)]

The students interviewed had a poor understanding of aspects related to the concept of reactivity. The most significant misconceptions revealed by these interviews are reflected below.

misunderstanding arises probably because students are aware that, on heating, the rate of the reaction increases, and that a catalyst also increases the rate of reaction. The heating can have both a kinetic and a thermodynamic effect. A catalyst has only a kinetic effect.

In everyday usage the word catalyst is not limited to substances. Change or action may be "catalysed" by all manner of non-substantial things. This may help foster the persistence of this misconception in chemistry.

D.	non spontaneous because Na had to be heated.	11,0	17,9
E.	catalysed because the *heat supplied* was a catalyst for the reaction.	14,2	13,2

Discussion.

Students were presented with a variety of distractors testing a number of misconceptions. Response (B) demonstrates that students' conception of an endothermic, or exothermic reaction is not clear. The overall reaction is exothermic as reflected by about 20% of both samples choosing the correct option (A).
Approximately 23% and 12% of the respective groups chose option (C), indicating that the reaction is spontaneous because the reaction is rapid. The existence of this view was shown in question 3.

Options B + D + E all focus on pre-heating. All these attach more importance to this, than the subsequent exothermic reaction. 48% of standard 8 & 10 therefore completely misunderstood the purpose of heating the sodium, although the majority must have seen it demonstrated.

Interviews conducted amongst the standard eight students showed that "heating " is regarded by some as catalysing. Indeed in both groups about 13% of the students chose option (E). This

Question 4.

Objective: To test whether students can distinguish between exothermic and endothermic reactions.

An exothermic reaction is a reaction in which energy is liberated in the overall reaction. In this question the heating of sodium is effectively providing activation energy. However the overall reaction of sodium with oxygen is an exothermic reaction. "Heat" cannot be considered as a catalyst. A catalyst for chemical reactions is a substance.

Question 4

When Na is heated in a deflagrating spoon, and then inserted in a gas jar of oxygen, there is a vigorous reaction with oxygen accompanied by the emission of light. The reaction of Na with *oxygen* can be considered to be

	Options	Phase 1 Std.8students %/option	Phase 1 Std.10 students %/option
-	No response	0,7	0,4
#A.	exothermic because energy is *liberated* in the form of light.	37,4	40,0
B.	endothermic because Na was *heated before* the reaction could take place.	23,2	17,0
C.	spontaneous because the reaction was *rapid*.	13,4	11,5

respective groups chose this option, illustrating that they perceive a spontaneous reaction as one that takes place without any delay. This view was also expressed by the students that were interviewed. This misunderstanding of the term spontaneous is probably due to it's everyday usage. The term is usually meant to imply that the act is voluntary or taking place at it's own accord and without external incitement. By this term, sudden movement is also implied.
About 20% of the standard 8 and 37% of the standard 10 students felt that a spontaneous reaction takes place without heating. This may be reflecting the same basic view, namely that it takes place without delay. If so, then 80% to 90% of all students hold similar views on spontaneity.

Question 3.

Objective: To test students perception of the concept spontaneous reaction.

A spontaneous reaction is a reaction that is thermodynamically favourable. However the rate at which the reaction will occur is not predictable. A spontaneous reaction may give off or absorb energy i.e both endothermic and exothermic reactions can be spontaneous.

The shortness of time lag for the reaction to occur is not a criterion for the spontaneity of the reaction. Time falls in the province of kinetics.

ΔG is the criterion for spontaneity.

Question 3

A spontaneous reaction is a reaction that

	Options	Phase 2 Std.8 students %/option	Phase 1 Std.10 students %/Option
-	No response	-	-
A.	always gives off energy.	7,8	1,7
B.	always absorbs energy.	2,4	1,3
C.	takes place without any delay.	58,4	54,0
D.	occurs without heating it.	20,4	37,0
#E.	can occur, however it could be fast or slow.	10,9	6,0

Discussion.

Option (C) was the most popular response. About 58% and 54% of the

C.	K will react with *more* oxygen than Na.	3,7	5,5
D.	the reactivity series can be used to predict which metal would react the fastest with sulphur.	7,3	8,9
E.	None of the above statements is correct.	6,6	11,1

Discussion.

A fairly large percentage of both groups chose the correct option (B). This answer was an obvious choice, and it is surprising that not more than 66% chose it.

The choice of options (A) and (D), totaling about 24% of both the groups of students, indicates a belief that the relative speed with which the metals react can be deduced from the reactivity series. Choice A is probably a relatively strong distractor as many students have seen the reactions concerned.

Only a small percentage of the students chose option (C), indicating in effect their belief that reactivity is related to stoichiometry.

Question 2.

Objective: To ascertain students interpretation of the reactivity series.

From the given reactivity series it is not possible to predict the rate at which the respective metals will react. Even though potassium is above sodium in the reactivity series, it does not necessarily imply that potassium will react faster with oxygen, nor that it will react with more oxygen. The latter can be determined from the stoichiometry of the balanced equation of the reaction. Both the kinetics as well as the thermodynamics of the reaction are in some way implicated in the term reactivity. Gold occupies the lowest position in the reactivity series attached to the questionnaire.

Question 2

The following statements are given below:

Use the accompanying reactivity series for metals and hence choose the *most* appropriate response:

	Options	Phase 1 Std. 8 students %/option	Phase 1 Std.10 students %/Option
-	No response	0,7	2,1
A.	K reacts *faster* with oxygen than Na does.	15,9	14,9
#B.	The least reactive metal is Au.	65,9	57,4

Some students also felt that a catalyst "initiates " a reaction. This is reflected in those who chose C and E (= 12 % std. 8; 14% std. 10). This view is not unreasonable as many reactions proceed extremely slowly without a catalyst. It therefore may appear as if reactions are initiated by catalysts in some cases.

	Options	Phase 1 Std. 8 students %/Option	Phase 1 Std. 10 students %/option
-	No response	-	-
A.	I	78,8	75,3
B.	II	1,5	3,4
C.	III	2,7	0,4
#D	IV	7,5	6,8
E	III & IV	9,5	14,0

Discussion.

The results of this question give some cause for concern. Approximately 75% of both the standard 8 and the standard 10 students believed that a catalyst speeds up a reaction without taking part in the reaction. This probably stems from the idea that because a catalyst undergoes no overall chemical change, it does not take part in the reaction. The idea of regeneration as the reaction proceeds is missed.

One standard 8 textbook[35] used by students transmitted this misconception. The textbook stated that "a catalyst speeds the rate of a reaction without participating in the reaction". Students at standard 10 level retained this misconception; they had used the same textbook when they were in standard 8. A large percentage of the students in standard eight used this textbook as a major source of instruction. Standard 10 students also used the standard 10 version of the physical science textbook by the same author. The same misconception was still evident.

Question 1

Objective: To test students understanding of the term catalyst.

Chemical reactions have two fundamental aspects. Firstly there is the rate at which the reaction occurs and secondly there is the position of the equilibrium. Catalysts are continuously regenerated during the conversion of reactant to product. Because they are regenerated it does not mean that they do not take part in the reaction. A catalyst affects the rate of the reaction and not the yield of the products.
If the reaction is thermodynamically unfavourable the addition of a catalyst will not make it thermodynamically favourable.

Question 1

I. A catalyst speeds up the *rate* of the reaction without taking part in the reaction.

II. A catalyst increases the *yield* of the products in a reaction.

III. A catalyst *initiates* a reaction.

IV. A catalyst increases the rate of the reaction.

Which of the above statements do you consider to be definitely appropriate?

# indicates correct response

Students were directed to use the following reactivity series in the questions unless otherwise stated. This reactivity series has been taken from a standard 8 Physical Science textbook without any modification.

Reactivity series for metals

K

Ba

Ca

Na

Mg

Al

Zn

Fe

Pb

(H)

Cu

Hg

Ag

Au

CHAPTER 5: QUESTIONNAIRES

An analysis of the reactivity questionnaire is undertaken first. Thereafter the analysis of the rate and equilibrium questionnaire follows. The rate and equilibrium questionnaire contains both multiple-choice questions and open ended questions.

5.1 Analysis of responses to the reactivity questionnaire.

The original questionnaire appears in Appendix A1.
Both the standard 8 and 10 students were presented with a variety of questions which aimed to test their understanding of reactivity and related concepts. In this section, the responses of the students are discussed on a question-by-question basis.

The objective for each of the eight multiple choice questions is given, together with some explanatory remarks. This is followed by the multiple-choice options which are individually analysed. There is brief discussion of the choice of options by the respondents.

The correct response is marked with an #, and the percentage of students from the respective standards selecting each response is indicated for each question.

Question 1

Objective: What information is extracted from the stoichiometric equation?

How far a reaction goes and how fast a reaction is, cannot be predicted on the basis of a balanced chemical equation. Quantitative information on rate can be retrieved from the rate equation, which is obtained from experimental data. The rate equation may be of any order and therefore we cannot make a quantitative prediction from the balanced chemical equation. In some cases the rate law happens to reflect the stoichiometry of the reaction, but it is important to note that this is not always the case. The rate law is something arrived at by *experiment* and cannot be inferred simply by looking at the reaction equation[32].

Question 1

The balanced chemical equation for the reaction between hydrogen and nitric oxide is

$$2H_2 + 2NO \longrightarrow 2H_2O + N_2$$

Given this equation decide how the rate of the reaction is influenced by doubling the concentration of NO:

5.2 Analysis of responses to the rate and equilibrium questionnaire.

The original questionnaire appears in appendix B1. Standard 10 students were presented with a variety of questions which tested their understanding of reactivity and related concepts such as rates of reaction and chemical equilibrium.

Students were presented with seven multiple-choice questions and two open-ended questions. The correct response for the multiple-choice questions is marked with an #, and the percentage of students selecting each response is indicated.

The objective for each of the seven multiple choice questions and the open ended questions is given, together with some explanatory remarks. This is followed by the multiple-choice and open-ended questions which are individually analysed. There is brief discussion of the choice of options by the respondents.

Some of the questions in this research study had been used in a questionnaire designed to test the misconceptions of a group of South African teachers on aspects of rate of reaction and chemical equilibrium[8]. Other questions in that study were similar to those in this research. Where the questions in the earlier study are identical to this study, percentages for all the options chosen in the earlier study are given. Where the questions in that study are similar to those in this study, percentages for the principal or secondary misconception relevant to this study are given.

D.	The order of the reactivity series for the metals *never* changes irrespective of the substances they react with.	44,3	37,9
#E.	None of the above statements is correct.	17,1	9,8

Discussion.

A large percentage of both groups chose option (D), that the position of the elements in a reactivity series is invariant. A fairly large percentage once again take the reactivity series to be some sort of a "rate series". Since this is already shown to be a widely held misconception, it is understandable that this should happen. Hence the percentage choosing option D might well be higher if there were other, less popular distractors.

Question 8

Objective: To determine whether students take the position of the elements in a reactivity series to be invariant.

Elements high up in the series do not have greater energy than elements lower in the series. The order of the reactivity series is not invariant. Meek[24] points out that there are many activity series although there is only one electrochemical series.
The relative rates at which hydrogen is liberated can only be obtained from the measured rates of the reactions concerned.

Question 8

Which of the following statements about the metal reactivity series is true?

	Options	Phase 1 std.8 students % /option	Phase 1 std.10 students % /option
-	No response	-	0,4
A.	Elements high up in the series have a lot of energy.	10,0	8,5
B.	Metals higher up in the series will react *faster* with solutions of metal salts than metals lower down.	22,5	33,6
C.	These metals immediately above hydrogen will react with dilute acids to produce hydrogen *faster* than a metal further up.	6,1	9,8

Discussion.

Once ag in the student responses indicate that more than half of them hol : the view that a reactivity series is a series that gives information about the speed with which the element will react.
Distractors (A) & (B) reflect the above assertion.
Only about 20% correctly indicated that the rates of reaction could not be predicted.

	Options	Phase 1 Std.8 student % /option	Phase 1 Std.10students %/option
-	No response	1,0	0,4
A.	The reaction in test tube (2) will be *faster* than that in test tube (1), because chlorine is *higher up* in the reactivity series from iodine than from bromine.	13,5	11,1
B.	The reaction in test tube (1) will be *faster* than that in test tube (2), because bromine is more reactive than iodine.	45,3	45,1
#C.	The *spe d* at which the reaction in the respective test tubes will take place cannot be predicted from the reactivity. series	20,6	17,9
D.	The reaction of chlorine with both solutions will not be spontaneous because *no heat* is supplied.	10,3	12,8
E	None of the above statements is correct.	9,3	12,8

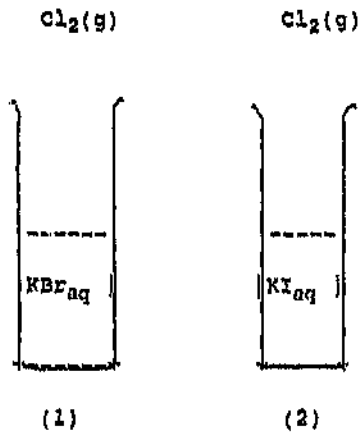
Question 7.

Objective: Interpretation of the halogen reactivity series.

Once more the speed with which a reaction takes place cannot be predicted from the halogen reactivity series. Chlorine being higher up in the reactivity series from bromine and higher up still from iodine, does not necessarily imply that it will react faster with potassium iodide solution than with potassium bromide solution. Chlorine can however displace both bromine and iodine from their respective salts.

Question 7

Chlorine is bubbled at the same rate through solutions of KI and KBr, in the respective test tubes (1) and (2). The solutions are of equal concentrations and of equal volume. From the halogen reactivity series given below, the following can be concluded:



Halogen reactivity series

F_2

Cl_2

Br_2

I_2

	Options	Phase 1 Std. 8 students %/option	Phase 1 Std. 10 students %/option
-	No response	0,5	0,4
A.	I	7,6	7,2
B.	II	23,2	11,5
C.	I,II & III	34,9	44,7
#D.	IV	23,2	17,9
E.	III	10,7	18,3

Discussion.

Only about one fifth of both groups chose the correct option(D). In question 5, only 9% of the std.8 and 13% of the std.10 did not see a connection between rate and reactivity (option E) as compared to 23% std. 8 and 18% std. 10 in this question. A lower percentage could not see the connection between rate and reactivity in question 5. This is probably because of more plausible distractors in question 5. In question 6, higher percentages did not invoke a connection between reactivity and rate because the alternatives were coupled and thus the choices of options were less scattered.

Option (A) uses the term "readily" which is ambiguous as to whether it is kinetic or thermodynamic in sense. Hence option (A) is ambiguous. Option (C) includes I & probably indicates a kinetic interpretation of "readily" since II & III are "kinetic choices". Hence the overall kinetic choice is B + C + E = 69%, std 8; 74%, std 10.

Question 6.

Objective: To ascertain students interpretation of a reactivity series.

By using the reactivity series it is not possible to say which metal compounds would decompose readily or what the relative rates might be.

Meek[24] reports that literature figures for the minimum temperatures for decomposition of carbonates show wide variations. Hence the action of heat on carbonates should not be used in building up an activity series. The literature figures for magnesium carbonate vary from 230°C to 680°C, for example.

Meek[24] also points out that a reactivity series gives no information about the speed with which metals will react.

Question 6

Consider the following statements about the metal reactivity series.

I. Compounds of metals at the top of the series decompose *more readily* than compounds of metals at the bottom.

II. A reactivity series is a series in which the metal reacting the *fastest* is placed at the top.

III. A reactivity series predicts the *relative speeds* of reaction of metals when reacting with any substance.

IV. A reactivity series gives *no information* as to *how fast* a reaction of a metal would occur.

Which of the above statements would you consider to be most appropriate?

Students choosing these options may in part reflect the unclear manner in which some of the current standard B texts are written.

	Options	Phase 1 std.8 students %/options	Phase 1 std.10 students %/option
-	No response	0,5	0,9
A	Zinc will react *faster* than lead with the copper sulphate solution.	30,2	26,0
B	Zinc will react *slower* than lead with the copper sulphate solution.	5,1	5,5
C	Both metals would react with the same speed.	17,1	11,5
D	Copper will be deposited *more rapidly* in beaker (1) than in beaker (2) because zinc displaces copper ions *faster* than lead does.	37,5	43,4
#E	None of the above statements is correct.	9,2	12,8

Discussion.

All the options, except E, invoked a connection between reactivity and relative rates of reaction. Approximately 90% of both standard 8 and 10 students responded in this manner, with options A+D (60%) being the most favoured.

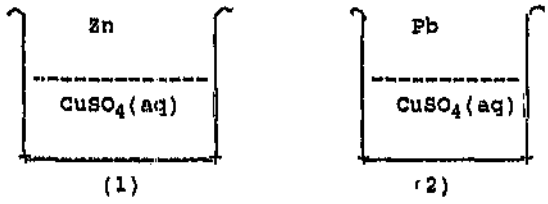
Question 5.

Objective: To ascertain students interpretation of a reactivity series.

The reactivity series used in this question is essentially a displacement series, giving no information on the relative rates at which metal ions will be displaced from the relevant salt solution. From a reactivity series one can predict which metal will be able to displace a metal ion from a solution of it's salt. The above is essentially an equilibrium statement.

Question 5

Equal numbers of moles of lead and zinc are placed in the same concentrations of copper sulphate solutions in respective beakers. (see diagram)



The reactions in the respective beakers are given below

1. $Zn(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$
2. $Pb(s) + CuSO_4(aq) \longrightarrow PbSO_4(aq) + Cu(s)$

Which of the following statements can be inferred from the accompanying metal reactivity series?

Question 5

Objective: Is a greater voltage taken as indicating greater current?

The E° values tell us whether or not the reactions are thermodynamically favourable, but not how fast reaction actually does occur.

As with any chemical rerction an electrochemical reaction (i.e. one conducted in a cell) once started, for example by closing a switch, may proceed at almost any conceivable rate. The electric current that passes in the external circuit is a manifestation of the rate of the overall cell reaction. Just as for chemical reactions generally, there is no necessary connection between the extent of a reaction at equilibrium and the rate of the reaction, so in electrochemistry, there is no necessary connection between cell emf and current. The current, but not the emf, is affected by cell construction and is dependent on the typical factors of reactions in general such as temperature, surface area etc. (Bradley and Brand[14]; Ogude[14])

Question 5

In the following electrochemical cell representations ammeters A_1 and A_2 are connected with identical copper wires to the respective cells.

the previous research study (see table). E^{o} values appear to be used as kinetic data by 50% of the teachers.

Thus although teachers were somewhat more successful, it appears that faulty teaching may be contributing to this misconception amongst students.

Options	Teachers/%
A	25,0
B	16.3
C	8,7
D	0
# E	50

	Options	Std. 10 students % /option
-	No response	0,9
A.	Reaction (i) is faster than reaction (ii) because the E° value is larger.	28,1
B.	Reaction (ii) is faster than reaction (i) because the E° value is smaller.	12,3
C.	Reaction (i) is faster because chlorine is a stronger oxidant than bromine.	20,4
D.	Reaction (ii) is faster because the concentration of Fe^{2+} is twice the concentration of Ni.	6,0
#E.	The faster of the two reactions cannot be predicted.	32,3

Discussion

Once again only 32% rejected the link between rate and cell emf. (see question 3).

It was once again noted that approximately 28% of the students chose option (A), indicating that a larger E° value implies a faster reaction.

About 20% of the students chose option (C) and, in doing so, indicated that the stronger the oxidising agent the greater the rate of the reaction.

25% of the teachers also thought that a larger E° value would result in a greater rate of reaction, as was reflected by their response an

Question 4

Objective: Are E° values taken as an indicator of the rate of the reaction?

The cell potentials of both reactions given in this question are positive, indicating that chemical energy can be converted to electrical energy spontaneously.

The cell potentials are not indicative of the rate at which the reactions take place. Even though the standard cell potential of $Ni(s)/Ni^{2+}(aq)//Cl_2(g)/Cl^-(aq)$ is much higher than that of $Fe^{2+}(aq)/Fe^{3+}(aq)//Br_2(g)/Br^-(aq)$, it cannot be concluded that the first reaction is faster. While the cell potential enables one to predict whether a reaction can occur spontaneously, it does not allow one to infer that it will proceed rapidly or even at a measurable rate.

The kinetics of reactions also cannot be extracted from the stoichiometric equations.

Question 4

Standard cell potentials for the following reactions are given below.

(i) $Cl_2 + Ni = Ni^{2+} + 2Cl^-$ $E^{\circ} = +1.60$ V

(ii) $Br_2 + 2Fe^{2+} = 2Br^- + 2Fe^{3+}$ $E^{\circ} = +0.29$ V

From these data it can be concluded that:

Approximately 70% linked E^{o} values to the rates of reaction by collectively choosing options (A+B+C+E).
Consequently they deduce from this that a catalyst would affect the E^{o} value since a catalyst affects the rate of a reaction.
The poor success with this question suggests that many students are unclear as to the meaning of E^{o}. Ogude[14] has found much evidence for this amongst standard 10 and university students. Students perceived that both an ammeter and a voltmeter gave the same information. Thus a voltmeter reading was taken as giving information about the rate at which a reaction occurs.

Current and potential difference are undifferentiated by many students, just as rate and equilibrium or thermodynamics are.

II. Reaction 2 is exothermic.

III. Reaction 1 is slower than reaction 2

IV. Adding a catalyst can speed up the reaction and thus change the E° value of the respectivc reactions.

V. None of the above statements is true.

Choose the correct statement(s)

	Options	Std. 10 students %/option
-	No response	0,4
A.	III	6,0
B.	I & II	29,8
C.	IV	14,0
#D.	V	29,8
E.	I	20,0

Discussion.

Only 30% of the students chose correctly and rejected the idea that cell emf is related to reaction rate. A similar percentage chose option (B). These students felt that a spontaneous reaction is a fast reaction and also that a negative E° value implies that it is an exothermic reaction.

Question 3

Objective: How are standard cell potentials interpreted?

From the standard electrode potentials a positive E° value corresponds to a negative ΔG° value for the appropriate cell reaction.

This approach can also be used to predict the "spontaneous" direction of a reaction based on a table of E° values.

A negative E° value is not indicative of an exothermic reaction: the latter is indicated by a negative ΔH° value. The E° value may also not necessarily tell one anything about the total heat evolved, as is indicated by the equation $-nFE^\circ = \Delta H^\circ - T\Delta S^\circ$. The larger the change in entropy the bigger the difference between $-nFE^\circ$ and ΔH°.

A catalyst may affect the rate of a reaction, but it does not affect the E° value. E° values tell us nothing about reaction rates.

Question 3

The *standard cell* potentials for the following hypothetical reactions are given below:

(1) A + B --------> C + D $\quad E^\circ = +1.1$ V

(2) E + F --------> G + H $\quad E^\circ = -0.5$ V

From these data the following can be concluded

I. Reaction 1 is a spontaneous reaction and therefore a faster reaction

Options	Teachers/%
A	37,5
B	-
# C	50
D	-
E	-

Where options in the previous research were different, no percentages are given.

Choose the correct statement(s)

	Options	Std.10 students
-	No response	0,4
A	III	12,3
B	I,II, V	34,9
*C	IV	22,6
D	V	22,6
E	I	7,2

Discussion

Approximately 19% of the students illustrated by their response (option A+E) that an exothermic reaction is always faster than an endothermic reaction. Approximately 23% of the students indicated that an exothermic reaction is spontaneous and an endothermic reaction is non spontaneous.

In a previous survey by the author[10] with a similar question, 37.5% of the teachers thought that exothermic reactions are always faster than endothermic reactions. 50% of the teachers chose the correct option as compared to only 23% of the students. The teachers experience and further education may have been responsible for less guessing, since the nature of the distractors in the respective questionnaires was similar.

Thus teachers may be imparting faulty information unwittingly to the students.

Question 2.

Objective: Are endothermic reactions, considered to be always slower than exothermic reactions?

Generally exothermic reactions are faster than endothermic reactions. However it cannot be conclusively said that exothermic reactions are faster than endothermic reactions. There are endothermic[33] reactions that are faster than exothermic reactions. For example, the endothermic reaction between hydrated barium hydroxide and ammonium chloride[33] is relatively fast in contrast to the exothermic reaction between hydrogen and oxygen. Thus by looking at the $\triangle$H values it cannot be concluded as to which reaction is fast and which reaction is slow.

Question 2

The chemical equations given below represent two hypothetical reactions.

$$A + B \longrightarrow C + D \qquad \triangle H = -x \text{ kJ} \quad (1)$$

$$D + E \longrightarrow F + G \qquad \triangle H = +y \text{ kJ} \quad (2)$$

If the two reactions occur at the same temperature which one of the following statements is correct?

I. Reaction 1 occurs *rapidly*.

II. Reaction 2 occurs *slowly*.

III. Reaction 1 is *always* faster than reaction 2.

IV. Reaction 2 *may* be faster than reaction 1.

V. Reaction (1) is spontaneous and reaction (2) is non spontaneous.

The teachers thus appeared to share the same misconception as the students. Student misconceptions could therefore have been due, in part, to faulty teaching.

Options	Teachers/%
A	54,0
B	4,2
C	4,2
D	8,2
E	29,4

	Options	Std.10 students %/option
-	No response	-
A.	the rate of the reaction would be doubled.	35,7
B.	the rate of the reaction would be four times greater.	15,3
C.	the rate of the reaction would be halved.	9,8
D.	there would be no effect on the rate of reaction.	14,5
#E.	the influence on the *rate* cannot be predicted from the balanced chemical equation alone.	24,7

Discussion.

Approximately 25% of the students responded correctly. Collectively about 60 % of the students used the coefficients to predict the outcome on the rate of the reaction. Exactly the same question was given to teachers in a survey by Bapoo, Bradley and Gerrans.[10] The table that follows gives the percentages for each option chosen by the teachers. It was disturbing to note that only 29.4% responded correctly by choosing option(E), whilst an overall percentage of 62% was obtained for options (A+B+C) collectively by the teachers.

2. Examples of responses linking reactivity series to rate.

R: The *faster* a metal reacts, the higher up it will be in the reactivity series table and the *slower* it reacts the lower down it is in the reactivity series table.

R: Reactivity is the ability an element has to react with another. It indicates whether an element can react *fast* or *slow*.

R: When compounds and substances are placed in a series according to how they react. The *faster* they react they are placed at the top of a series and the *slower* at the bottom of the series.

R: A reactivity series is a series in which elements are placed according to their *rapidness* in allowing a reaction to be carried out. The *faster* reacting elements are at the top and the *slower* at the bottom.

R: The reactivity series indicate the relative *speed* of metals when it reacts with a substance. The element at the top is most reactive and it gradually decreases coming down.

R: This indicates to us the increasing ability or power or decreasing ability or power of elements to react, i.e it indicates to us *how fast* it would take an element to react. e.g Potassium is more reactive than nickel because nickel occurs lower down in the reactivity series table than potassium. Therefore if nickel and potassium is to react with the same substance (separately of course) the reaction mixture concerning the potassium would produce results *faster* than the reaction mixture containing nickel.

Students responses to the concept of reactivity series.

1. Examples of responses giving circular explanations

R: The reactivity series indicates which substances are *highly reactive* and those which are not.

R: Indicates which substances are *highly reactive* and which are not highly reactive.

R: This is where the more *reactive* substance will be at the top and where the least reactive at the bottom.

R: It is the ordering of elements according to increasing or decreasing *reactivity*.

R: The pattern that the substances are placed from the ones that are *most volatile* to those that are the least volatile.

R: Reactivity series are either metals or the non metals(halogens) that form a series according to their *reactivity ability*.

R: Reactivity series is a series of metals according to *how "reactive"* they are.

R: It is how the elements is listed in the periodic table. From top to bottom and left to right

R: It is a series , ordering elements according to increasing or decreasing *activity*.

R: This is a specific arrangement where substances are classified according to how they take place in reactions. The series obviously ranges from substances of *high reactivity* to that of low reactivity.

R: The *rate* at which substances react with each other, degree of spontaneity of reactions.

R: How fast a metal or chemical will react with another substance. The *rate* at which the substance will react or whether it is a spontaneous reaction or not. Is a catalyst needed to begin a reaction? Is there any forms of energy given off e.g. heat, light?

R: This means how *quickly* or vigorously a metal would react with another.

R: How *fast or slow* the reactants will react with each other and if the reaction will take place spontaneously or non spontaneously with the aid of a catalyst.

R: Each substance has a certain reactivity which means that some substances react faster or more effective than others. Example copper is more reactive than zinc. A more reactive substance can accept electrons *faster*.

2. Examples of responses that gave circular explanations

R: Chemicals continuously react with one another, some chemicals are more reactive than others. The metals of group I and II are most reactive.

R: The term means how reactive a substance is. All elements in a periodic table have different reactivities.

R: How reactive a substance is increases from left to right.

3. Approximately 50% of the students indicated an implied relationship between a reactivity series and the electrochemical series. Approximately 4% of the 50% responses in this category are quoted below.

Some of the responses from the students pertaining to the categories indicated above are given below.

Student responses have been reflected using the letter "R". The responses are reflected as they appear on the original rate and equilibrium questionnaire. Discussions of the responses will follow later.

Students responses to the concept of reactivity

1. Examples of responses linking reactivity with rate of reaction.

R: When two or more substances combine, they form a mixture or a compound because electrons have been transferred from one substance to another i.e. a reaction has occurred. Reactivity is probably a measure of the *rate* at which reactions occur.

R: The *rate* at which metals react. How *fast* or how slow they form or disintegrate.

R: Reactivity is a measure of how readily a substance combine with another i e *how fast* a substance reacts.

R: The *rate* at which a compound or an element would react. How fast or how slow this would be done. A catalyst would increase the reactivity.

R: It probably refers to the ability of chemicals to react *quickly or slowly*, spontaneously or non spontaneously.

The responses for the open ended questions can be respectively assigned to three distinct categories.
These categories are given below. The responses of 235 standard 10 students to both these questions were analysed.

Reactivity

1. About 50% of the students linked their descriptions of reactivity to rate. Approximately 11% of the 50% responses in this category are quoted below.

2. Intelligible but "circular" explanations of the concept of reactivity were given by approximately 10% of the students, indicating a lack of explanatory power.
   Approximately 12% of the 10% responses in this category are quoted below.

3. Approximately 40% of the responses were unintelligible. These have not been quoted.

Reactivity Series

1. Approximately 10% of the students gave a circular explanation of the concept of a reactivity series. The term reactivity was used to explain the concept reactivity series. Approximately 40% of the 10% responses in this category are quoted below.

2. Approximately 40% of the students believed that a reactivity series was essentially a rate series. Approximately 7% of the of the 40% responses in this category are quoted below.

equilibrium system. Teachers did only slightly better with 37,5% choosing this option.

Once again there is evidence that teachers are responsible for transmitting erroneous knowledge.

Options	Teacher/%
A	0
B	50
# C	37,5
D	0
E	12,5

Also, once again, there seems to be a tendency for teachers choices to be less scattered. This may be a sign that further education has resulted in less guessing perhaps but no great improvement in understanding. However this statement may be invalid as the number of teachers is small.

Open ended question on the following concepts

Standard 10 students were tested on their understanding of the terms reactivity and reactivity series by means of the following open-ended questions.

8. Explain in about five lines what you understand by the following term(s).

8.1 Reactivity

8.2 Reactivity series.

increasing the temperature of the system:

	Options	Std. 10 students % /option
-	No response	-
A.	Increases the rate of the forward reaction only.	17,9
B.	Increases the rate of the reverse reaction only.	30,2
#C.	Increases the rate of both the forward and reverse reactions.	33,6
D.	Decreases the rate of the reverse reaction since the reverse reaction is endothermic.	11,5
E.	Has no effect on the rates of either the forward or the reverse reaction.	6,8

Discussion

About 30% of the students chose option (B), probably because if the temperature of an exothermic reaction is increased the reverse endothermic process is favoured.

Approximately 50% of the teachers chose the same option(B) for exactly the same question in the previous research conducted by the author[14].

Approximately 34% of the students chose the correct option, indicating that they do not have a compartmental view of

Question 7

Objective: Are students aware that increasing the temperature of a reaction at equilibrium, increases the rate of both the endothermic and exothermic processes?

Increasing the temperature of a reaction system always increases the rate of the reaction, irrespective of whether the reaction is exothermic or endothermic. Increasing the temperature will increase the rate of both the forward and reverse reactions; it does not solely increase, either the forward or reverse rates.

The reverse reaction in this question will be *more sensitive* to temperature changes than the forward reaction. Because the forward reaction is exothermic, the activation energy of the reverse reaction will be greater than that of the forward reaction. Hence the rate constant for the forward reaction will not be affected to the same extent as the reverse reaction. Consequently K_{eq} which is related to the rate constants as given below, will be decreased as temperature is increased.

$$K_{eq} = k_f/k_r$$

k_r = rate constant for the reverse reaction.

k_f = rate constant for the forward reaction.

K_{eq} = equilibrium constant.

Hence the proportion of reactants at equilibrium will be increased by temperature increase.

Question 7

In the equilibrium reaction represented by the following equation

$$3H_2 + N_2 \rightleftharpoons 2NH_3 \qquad \Delta H = -92kJ$$

D.	Fluorine accepts electrons *faster* than iodine as is indicated by fluorine having a larger E° value.	28,9
#E.	None of the above statements is correct.	18,3

Discussion.

Approximately 29% of the students indicated that the larger the E° of the half cell reaction the faster the reactant would accept electrons. This was shown by choosing option (D). Another 12% chose option (B) which also relates reaction rates to E° values. Collectively 41% chose option (D+B) thus linking rate to E°. About 27% of the students chose option (A) and thus decided that fluorine is the strongest reducing agent. These students may have applied the sign convention incorrectly, or been confused between oxidation and reduction and the direction of electron transfer.

Question 6

Objective: How are standard reductic· potentials interpreted?

The E^{o} values of the respective couples can be used to predict the spontaneous direction of the reactions.
Standard reduction potentials indicate in relative terms the favourable direction of the half cell reaction, and they give no information as to the rate of the half reaction.
By convention the greater the standard reduction potential, the stronger the reactant is as an oxidising agent.

Question 6

The ·*andard* reduction potentials for the following half reactions are given below.

$F_2(g) + 2e^- \text{--------} > 2F^-(aq)$ $\quad E^{o} = +2.87$ V

$Cl_2(g) + 2e^- \text{--------} > 2Cl^-(aq)$ $\quad E^{o} = +1.36$ V

$Br_2(l) + 2e^- \text{--------} > 2Br^-(aq)$ $\quad E^{o} = +1.06$ V

$I_2(s) + 2e^- \text{--------} > 2I^-(aq)$ $\quad E^{o} = +0.54$ V

The following information can be inferred from the data given.

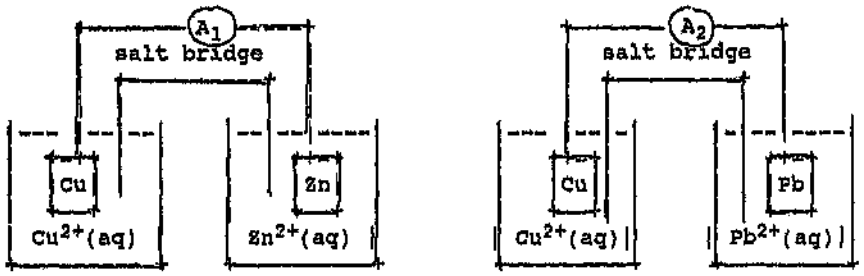
	Options	Std. 10 students % /option
-	No response	1,7
A.	Fluorine is the strongest reducing agent.	26,4
B.	Fluorine will react *faster* than iodine when reacting with sodium.	11,9
C.	Iodine is the strongest oxidizing agent.	12,8

Discussion.

About 27% of the students indicated that ammeter A_1 would have a greater reading than ammeter A_2 since the standard cell potential for (1) is greater than that of (2). This is possibly because students were applying Ohm's law to this situation. At this stage the students would have already been introduced to the application of Ohm's law to DC electric circuits.

Options A, B and D all imply a link between reaction rate and cell emf. The 73% who chose these options probably include the same individuals as those 68% (Q4) and 70% (Q3) found previously.

The respective *standard cell potentials* are given below.



(1) (2)

(1) $Cu^{2+}(aq) + Zn(s) \longrightarrow Zn^{2+}(aq) + Cu(s)$ $E^{\circ} = 1.1$ V

(2) $Cu^{2+}(aq) + Pb(s) \longrightarrow Pb^{2+}(aq) + Cu(s)$ $E^{\circ} = 0.47$ V

From these data it can be concluded that:

	Options	Std. 10 students %/options
-	No response	-
A	Zn will go *faster* into solution than Pb.	35,3
B	Pb will go *faster* into solution than Zn.	10,6
#C	The ammeter indicating the larger current cannot be predicted.	5,5
D	Greater cell voltage implies greater cell current.	27,2
E	None of the above statements is correct.	21,3

reaction and a reaction coordinate diagram are presented in the standard 10 syllabus, both of these are implicitly linked to a one-step mechanism. This sort of mechanism is logically connected to the balanced stochiometric equation for the reaction. Hence, the misconception that the rate law is predictable from the balanced chemical equation, is fostered by the kind of microscopic - level explanations that are offered by student textbooks.

ΔH of reaction values were also invested with kinetic significance by both the teachers and the standard 10 students (Bapoo et al)[10]. This is also not unreasonable although incorrect. The use of reaction coordinate diagrams showing activation energy and ΔH, could have helped ameliorate this misconception. This is done in some student textbooks.

Spontaneous reaction

From the three components of the investigation, the following misconceptions were found to be prevalent amongst the students.

1. Interviews of standard 8 students.

a) A spontaneous reaction is a reaction that takes place without any delay.

b) A spontaneous reaction is a reaction that takes place without heating.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

a) A spontaneous reaction is a reaction that takes place without any delay. (8)58%, (10)54%

3. Responses to the rate and equilibrium questionnaire by standard 10 students and teachers.

a) The effects of change of reactant concentration on the rate of the reaction are inferred from a balanced chemical equation.(10)60%, (T)62%

b) A positive ΔH of reaction implies a slower reaction than one with a negative ΔH.(10)23%, (T)37,5%

The standard 8 students that were interviewed indicated that increasing the amounts of the reactants would decrease the rate of the reaction because a longer time would be needed for the reaction to reach completion.
The experiments on reactions of metals in oxygen could perhaps be taken as evidence for such an erroneous view. A larger piece of metal in oxygen would take a longer time for completion of the reaction.
By the time the standard 8 students are taught the section on "reactions of metals" they have already completed the section on speed in physics. In this context also the observation that the greater the distance the greater the time can lead students to infer erroneously that the speed is less.

About 60% of the standard 10 students and 62% of the teachers predicted some sort of a rate law from the balanced equation. The implication is that neither the standard 10 students, nor their teachers have grasped the basic microscopic-level concept of reaction mechanism. Although a microscopic collision model of

Perhaps the above quote is but one of the possible sources of the above misconception.

The process of heating was also thought to be akin to catalysing probably because both heating and catalysing increase the rate of a reaction.

The standard 8 students misunderstanding of the functioning of a catalyst may be understandable since it receives little attention at that level. However the standard 10 students should have had a better understanding since they are formally taught about catalysis with activation energy diagrams at this level. In fact this was not evident. This exemplifies perhaps the persistence of misconceptions established previously.

Rate of reaction

From the three components of the investigation, the following misconceptions were found to be prevalent to varying degrees.

1. Interviews of standard 8 students.

a) Increasing the amount of the reactants would decrease the rate of the reaction because a longer time would be needed for the reaction to reach completion.

b) No reference made to time.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

No direct question was asked.(see reactivity series).

1. Interviews of standard 8 students.

a) A catalyst increases the rate of the reaction without taking part in the reaction.

b) "Heating " is regarded as a catalytic process.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

a) A catalyst increases the rate of the reaction without taking part in the reaction. (8)79%, (10)76%.

b) "Heating " is regarded as a catalytic process.(8)14%, (10)13%

c) A catalyst *initiates* (italics in questionnaire) a reaction. (8)12%, (10)14%

3. Responses to the rate and equilibrium questionnaire by standard 10 students.

No question directly related to this concept.

A large percentage of standard 8 students believed that a catalyst increases the rate of a reaction *without taking part in the reaction*. This misconception was still equally prevalent amongst the standard 10 students.

The following quote pertaining to the concept of a catalyst appeared in [35(a)], a standard 8 textbook that has been extensively used in most schools. The textbook indicates that "Oxygen can be prepared on a large scale in the laboratory by making use of the apparatus shown in figure 9.1.....The small amount of manganese dioxide added to the potassium chlorate, only speeds up the reaction (we call it a catalyst), *but does not participate in the reaction*"(my italics). A similar view is expressed in [36(a)] a standard 10 textbook that was used extensively by the students.

table continued.

1c	-	-	Q2(p 86) Q3(p 89) Q4(p 92) Q5(p 95) Q6(p 98)
2a	-	-	Q4(p 92)
2b	I(p32 line 5 up)	-	Q6(p 98)
2c	-	-	Q5(p 95)
3a	-	Q1(p 62)	-
3b	-	Q1(p 62)	-
3c	-	Q1(p 62)	-
3d	I(p42 line 15) I(p45 line 3)	-	-
3e	I(p45 line 3)	Q1(p 62)	-
4a	I(pp 26-41)	Q2(p 65) Q5(p 72) Q6(p 75) Q7(p 77)	OEQ(p 102)
4b	I(pp 41-43)	Q3(p 67) Q4(p 69) Q7(p 77)	Q2(p 86) Q3(p 89)
4c	-	-	OEQ(p 102)
4d	-	Q8(80)	-
4e	I(pp 26-41)	-	OEQ(p 102)

OEQ denotes open ended question.

Catalysis

From the three components of the investigation the following misconceptions were found to be prevalent amongst the students involved.

CHAPTER 6: SUMMARY OF CONCEPTUAL DIFFICULTIES AND DISCUSSION OF THEIR ORIGIN

This chapter links the original specific research questions (Res. Q) on pages 20 to 22, to the outcomes from the interviews and questionnaires. The table below aims to facilitate the linkage. This chapter also lists misconceptions, identified in relation to catalysis, rate of reaction, spontaneous reaction, endothermic and exothermic reactions and activation energy, electrochemical cells, reactivity and reactivity series. This is followed by a discussion of the possible origin of the misconceptions.

Evidence is presented from the following three components of this phase of the research:

1. interviews of standard 8 students;
2. responses to reactivity questionnaire by standard 8 & 10 students;
3. responses to rate and equilibrium questionnaire by standard 10 students.

For (3) the prevalence of misconceptions found amongst teachers in the earlier study8 is also described.

Table

Res.Q	Interview	Std.8 Quest.	Std.10 Quest.
1a	-	-	Q2(p 86)
1b	-	-	Q7(p 100)

Table 3 (continued)

6D	29%	-	Greater standard reduction potential of half cell implies oxidant accepts electrons faster.
7(A+B+D)	60%	50%	A temperature increase on a system at equilibrium affects the rate of either the forward or reverse reaction only.

Overall, despite the additional learning opportunities and their greater maturity, the standard 10 students answered very similarly to standard 8 students. Also there are several points of similarity in the misconceptions of standard 10 students and the teachers.

Table 3

Question	Std. 10	Teacher	Misconceptions
1(A+B+C)	60%	62%	Concentration effect on rate of reaction inferred from balanced chemical equation.
2(A+E)	19,5%	37,5%	Exothermic reactions are always faster than endothermic reactions.
2B	35%	37,5	A spontaneous reaction cannot be a slow reaction.
2D	23%	37,5%	$-\Delta H$ implies reaction spontaneous; ΔH implies reaction non spontaneous.
3(A+B+C+E)	70%	-	Linked E° values to rate.
4(A+B+C+D)	68%	50%	Linked E° values to rate.
4A	28%	25%	Greater E° value implies greater rate of reaction.
4C	20%	9%	The stronger the oxidant in a reaction the faster the reaction.
5(A+B+D+)	73%	-	Link E° values to rate of reaction.

who chose responses invoking a connection of reactivity with relative rates of reaction.

Table 2

Question	std. 8	std.10
2(A+D)	23%	24%
5(A+B+C+D)	90%	87%
6(A+B+C+E)	74%	82%
7(A+B)	59%	56%
8(B+C)	28%	44%

This suggests that as much as 90% may believe in this link. Where other options are particularly attractive, the % students choosing this link is reduced.

2. Comparison of Standard 10 students with teachers

Table 3 shows the comparison in respect of the concepts, rate of reaction, exothermic/endothermic reaction, electrochemical cell and enthalpy. Misconceptions of standard 10 students suggested by responses to the rate and equilibrium questionnaire alongside those of teacher misconceptions deduced from responses to identical or similar questions in an earlier study are given.

Some of the concepts in the rate and equilibrium questionnaire were not tested amongst the teachers and therefore no percentages have been given in the relevant column. However wherever questions were similar, or the same, a comparison has been made.

Comparison of standard 8 with standard 10 students for the reactivity questionnaire.

Tables 1 shows this comparison in respect of the concepts, catalyst, spontaneous reaction and activation energy. Responses are drawn from questions 1,3,4 and 8.

Table 1

Question option	Std. 8	Std.10	Implied misconception
1A	79%	76%	A catalyst speeds up a reaction, without participating in the reaction.
3C	58%	54%	A spontaneous reaction takes place without delay.
3D	20%	37%	A spontaneous reaction occurs without heating.
4(B+D+E)	48%	48%	Activation energy confused with endothermicity.
4E	14%	13%	Heating is catalysing.
4C	13%	12%	A spontaneous reaction is rapid.
8D	44%	38%	Order of elements in the reactivity series is invariant.

Table 2 shows responses for questions 2,5,6,7 and 8. These questions were based on the reactivity series and each had more than one distractor related to *rate*. The percentages indicate those students

2. Students showed poor understanding of the concept of reactivity and reactivity series. Circular explanations were given i.e the word reactive was used to explain the term reactivity.

3. Students took the reactivity series and the electrochemical series as being synonymous. This became evident when terms like oxidising agent and electrode potentials were used to explain the concept of a reactivity series.

Summary of misconceptions

To summarise the analysis the following tables provide:

1. Comparison of possible misconceptions of standard 8 students with standard 10 students as suggested by responses to the standard 8 reactivity questionnaire. (Tables 1 and 2)
2. Comparison of possible misconceptions of standard 10 students with teachers as suggested by responses to the same multple-choice questions in the rate and equilibrium questionnaire and in an earlier study. (Table 3)

In studying the comparisons the following should be borne in mind. All questions in the reactivity questionnaire were answerable by standard 8 students in terms of the standard 8 syllabus. The concept of a catalyst is not in the standard 8 syllabus; however some simple teaching of this phenomenon is a common practice, when dealing with the preparation of oxygen from potassium chlorate (using manganese dioxide as a catalyst).

Standard 10 students could answer these standard 8 questions in terms of their memory of standard 8 work supplemented, of course, by their learning about aspects of rate of reaction, chemical equilibrium and electrochemical cells in standard 10.

3. Examples of responses linking reactivity series to electrochemical series.

R: The *standard electrode potential* of an electrode as reductant and oxidant in a specific series.

R: The series indicates the magnitude of how reactive a substance. The elements are arranged from *negative* E^{o} values to value of E^{o}*(positive)*. Reactivity can also be determined from the periodic table-increases down a group and decreases from left to right in a period.

R: Refers to *standard electrode potentials* decreasing from highest reducing agents to lowest reducing agents.

R: It basically distinguishes chemicals from each other according to its *potential*.

R: From the reactivity series one can conclude which reaction would be *spontaneous* and which reaction would be *non spontaneous*. One can also conclude which one of the chemicals would be the *stronger oxidising* agent and which one is the *stronger reducing* agent.

In view of these responses to the open-ended questions the following general observations can be made.

1. Thermodynamic or equilibrium considerations were clearly lacking in their explanations of the term reactivity. Words like rate, speed, fast, slow, quickly and readily were extensively used in the students explanations of the concept of reactivity. The majority seemed to be looking at the term only from a kinetic viewpoint.

may unwittingly be teaching that the electrochemical series gives kinetic information. Teachers and students are largely textbook oriented and the ambiguities of the standard 8 textbooks do nothing to counter this erroneous concept.

The following analogy appears in the standard 8 student textbook [35(g)] "In your class there is a pretty girl called Karen, who is going steady with John. The other boys are very jealous. As Thomas can no longer hide his affection an open confrontation occurs. Thomas is much stronger than John and by the following day everybody knows that Karen belongs to Thomas. *The weaker one has been displaced by the stronger.*"

This type of anthropomorphic thinking distracts the attention from the task of discovering a scientific explanation, by substituting an apparent but pseudo-explanation. Furthermore, like most analogies, the above example is liable to misinterpretation. Johnstone[2] indicates that sometimes analogies create more problems than they solve. Similarly Duit[38] and Dupin[39] stated that analogy may give birth to as many monsters as healthy babies. Learning fundamentally has to do with constructing similarities between the new and the already known. It is precisely this aspect that emphasizes the significance of analogies in a constructivist learning approach.

oxides and the reactivity of metals [35(d)]. This link is but one example of the very many that are implied throughout the two texts. Students could therefore be assuming that the positions of the elements in a reactivity series are invariant, irrespective of the nature of the reactants.

In [36(f)] it is stated that " .... we can arrange the metals in sequence from the most reactive (potassium) to the least reactive (mercury). Such a series is known as an activity series" (emboldened in text). Whether the terms activity and reactivity should be taken to mean one and the same thing is unclear.
Standard 8 students during interviews implied there is a relationship between a reactivity series and an electrochemical series, even though the electrochemical series is not in the standard 8 syllabus.

The standard 10 students had been taught about the electrochemical series in the context of the topic electrochemical cells. It is therefore less surprising that they should mistakenly link this series with the reactivity series already-established in standard 8. Attention is drawn to this tacit linkage to emphasize that the kinetic interpretation of the reactivity series by the standard 8 and 10 students, could lead to the kinetic interpretation of the electrochemical series.

Perhaps one source of the above link is teachers. Many standard 8 teachers were or had been teaching standard 10 students at some stage. They are thus familiar with the electrochemical series and

is still no indication of whether the speed or energetics is under consideration. What factors should be kept constant if the reactivity of the metals is considered, either in terms of the speed or the overall energetics of the reaction?

In [36(d)] it is quoted that "if we *assume* that the metal which reacts with oxygen holds onto oxygen strongly and one which is less vigorous gives off *oxygen* more easily our pattern appears as follows." Sodium is given above magnesium without any explanation.

In [36(e,h)] it is indicated that it must be remembered that *other* factors are not mentioned, and the chance to disclose some of the assumptions behind the interpretations of observations is lost.

Unjustified assumptions can tacitly lead to misconceptions. Where assumptions are made this should be clearly indicated.

Two currently available school texts were examined for the way in which they treat the conceptual aspects of reactivity and reactivity series.

In [35(b),35(e)] students are asked to work out an order of reactivity for the reaction of metals with:

(i) oxygen;

(ii) water.

However no clear criteria are given for arranging the metals in a reactivity series.

There is also an implied link between the decomposition of the metal

b) An implied relationship between a reactivity series and an electrochemical series (giving arbitrary values to the elements in a reactivity series). (10)50%

c) The elements in a reactivity series are arranged so that the element at the top will react faster with reactants than an element lower down.(10)40%

According to their responses on the reactivity questionnaire, standard 8 students usually regarded a reactivity series as a reaction rate series. Standard 10 students held the same view. As noted before, reactivity series are not reconsidered in standard 10. Standard 10 students thus retain their erroneously limited ideas from standard 8.

This is the outcome to be expected from the ambiguous way in which this concept is treated at a standard 8 level. No distinction is made in student textbooks between various approaches that could be used when comparing the reactivity of metals (see Meek[24] and Jenkins[26]).

In most textbooks there is also no mention of the very many *assumptions* made when interpreting the relevant experiments. For example, in reference to the displacement of one metal by another in solution, in [35(f)]:

"In all such displacement studies the *assumption* is that the metal higher in the reactivity series will in fact displace one lower in the series from one of it's salts in aqueous solutions and that by such displacement the displacing metal is to be regarded as more reactive". Although this statement is clear as far as it goes, there

and the solubility and alkalinity of the products formed. There is also an implied link between the decomposition of metal oxides and the reactivity of the metals [36(c)]. What the term vigour means, and what factors affect the vigour, is not indicated.

Reactivity Series

From the three components of the investigation, the following misunderstandings were found to be prevalent.

1. Interviews of standard 8 students.

a) The elements in a reactivity series are arranged so that the element at the top will react faster with reactants than an element lower down.

b) A reactivity series tells us how reactive a substance is.

c) An implied relationship between a reactivity series and an electrochemical series.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

a) Reactivity series is essentially a "rate series". It is a series that gives the relative rate of reaction of elements with the same reactant. (8)90%, (10)87%

b) The positions of the elements in a reactivity series are invariant, irrespective of the nature of the reactants. (8)44%, (10)40%

3. Responses to the rate and equilibrium questionnaire by standard 10 students.

(Open ended responses)

a) A "circular explanation" was given. (10) 10%

(i) the exothermicity of the combustion in oxygen,

(ii) the relative rates of oxidation, or

(iii) some roughly qualitative judgement that, for example the spectacular combustion of magnesium indicates the metal is more reactive, i.e. higher in a reactivity series, than copper.

It has been mentioned that the descriptions of the concept reactivity by standard 8 students were largely anthropomorphic. Terms such as vigour, violence, readiness, full of ze. and brightness of flame were used to explain the concept of reactivity, without defining what these terms mean. The following quotations from the respective textbooks illustrate that this judgement also applies to them. Selected terms of description have been underlined.

"From the experiments in this chapter, you will see that elements which undergo similar reactions are placed underneath each other in the table in the same group.....combustibility ,i.e. the *readiness* with which elements combine with oxygen will form the basis of your first series of investigations" [35(b)]. "Try to judge the *violence* of the reaction from the *brightness of the flame* (if they burn)" [35(a)].

"The rate at which hydrogen is generated indicates the degree of *violence* of the reaction. This suggests another method of comparing reactivities". [36(c)].

In the other textbook [36(a)] students are asked to arrange the metals in accordance with the *vigour* of the reaction with oxygen,

b) Terms used to explain the concept of reactivity were used in an anthropomorphic manner.

c) Reaction of metals with oxygen, water and metal salts were essentially judged visually from a kinetic viewpoint. Hardly any reference was made to overall energetics of the reactions.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

(See reactivity series)

3. Responses to the rate and equilibrium questionnaire by standard 10 students.

(open ended questions)

a) Explanations of the term reactivity were "circular" (10)10%

b) The term reactivity was essentially linked to rate. No consideration was given to the overall energetics. (10)40%

Standard 8 students seemed to describe reactivity either in terms of speed of reaction or in a non-scientific (or even anthropomorphic) manner. Standard 10 students could do no better, possibly because there is no further treatment of the reactivity concept after standard 8. In other words, the syllabus does not provide for the formal reconsideration of the concept in terms of rate, equilibrium and reaction enthalpy.

Two student textbooks were scrutinised to determine how the concept of reactivity is introduced in standard 8. It is not clear in these textbooks (when dealing with reactions of metals with oxygen) whether reactivity [35(b), 35(c)] and [36(b)] is judged by:

were used when answering this question. The students implicitly assumed that the reactivity series they learnt about in standard 8 and the electrochemical series they learnt about in standard 10, give the same information.

Since many students regarded the reactivity series as being based on reaction rates, it is not surprising that electrochemical quantities like E° were linked to reaction rates(see earlier Ogude et al[14]).

Attention has been drawn later, to this tacit linkage, when dealing with the concept of reactivity series. Many terms, properly used in relation to the thermodynamic aspects of reaction, like ΔH, E°, and spontaneous reaction, were interpreted in a kinetic sense by the standard 10 students.

There is a lack of emphasis during instruction on the distinction between thermodynamic and kinetic considerations when dealing with the topic reactivity. This seems likely to be instrumental in students persistently being unable to distinguish between the kinetic and thermodynamic aspects of reactions.

Reactivity

From the three components of the investigation, the following misunderstandings were found to be prevalent to varying degrees.

1. Interviews of standard 8 students.

a) All of the reactions were judged only according to speed (kinetics).

Electrochemical Series

From the three components of the investigation, the following misconceptions were found to be prevalent.

1. *Interviews of standard 8 students.*

   Students referred to the electrochemical series during the interviews about reactivity and reactivity series.

2. *Responses to the reactivity questionnaire by standard 8 & 10 students.*

   No questions on this concept in the standard 8 questionnaire.

3. *Responses to the rate and equilibrium questionnaire by standard 10 students and teachers.*

   a) More positive E^{O} values for the cell reaction are indicative of a faster reaction.(10)28%, (T)25%

   b) The stronger the oxidizing agent (as judged by E^{O} for the half reaction) the greater the rate of the reaction. (10)20%, (T)9%

   c) A greater cell voltage implies a greater cell current.(10)20%

   d) There is an implied link between an electrochemical series and a reactivity series (i.e they are synonymous with respect to the information they give.) (10)50% - open ended question.

It was evident that it is unclear as to what type of information can be extracted from the electrochemical series.

About 50% of the standard 10 students referred to the electrochemical series when responding to the open ended question on reactivity series. Terms like oxidising agent and cell potentials

b) Increasing the temperature of a reaction system increases either the rate of the forward or reverse reaction but does not affect the rate of both the endothermic and the exothermic process. (10)60%, (T)50%

In the question that focussed on the pre-heating of sodium, before it reacted with oxygen, approximately 48% of the students misunderstood the purpose of pre-heating. It is understandable if standard 8 students could not distinguish between activation energy and the endothermic nature of a reaction since these concepts are not formally taught at this level. The standard 10 students, however, had already dealt with activation energy, potential energy diagrams, exothermicity and endothermicity. Their understanding of this experiment nevertheless had not improved at all.

Standard 10 students exhibited related misconceptions about the connection between reaction rates and overall energy change ($\triangle H$). This may partly derive from the ambiguities of reactivity comparisons done in standard 8. If so, it would probably be reinforced by their teachers, since teachers exhibited a similar prevalence of misconceptions as indicated by Bapoo et al[10]. The standard 10 syllabus appears actually to invite the persistence of such misconceptions, because the $\triangle H$ concept is actually included as a sub-section of rates of reaction.

Temperature effects on a reaction system at equilibrium were also not clearly understood as was indicated earlier by Bradley et al[6,7].

The standard 10 students indicated that an endothermic reaction is non spontaneous. This might be a different manifestation logically derived from the erroneous concept quoted above. A significant percentage of teachers also indicated in an earlier study that an endothermic reaction is non spontaneous. Also a slow reaction was regarded as non-spontaneous because it was not considered energetic. Teachers seem therefore also to be a source of student misconceptions about spontaneity, as indicated by Bapoo et al[10] and Ogude et al[14].

It is evident from the above discussion that the term spontaneous was often interpreted in a kinetic sense rather than in a thermodynamic sense.

Endothermic and exothermic reactions and activation energy.

From the three components of the investigation, the following misconceptions were found to be prevalent.

1. Interviews of standard 8 students.

a) Could not distinguish between activation energy and endothermicity.

2. Responses to the reactivity questionnaire by standard 8 & 10 students.

a) Could not distinguish between pre-heating for activation energy and endothermicity. (8)48%, (10)48%

3. Responses to the rate and equilibrium questionnaire by standard 10 students and teachers.

a) Endothermic reactions cannot be faster than exothermic reactions. (10)19,5%, (T)37,5%

b) A spontaneous reaction is a reaction that takes place without heating. (8)20%, (10)37%

3. Responses to the rate and equilibrium questionnaire by standard 10 students and teachers.

a) Endothermic reactions are non spontaneous reactions.(10)23%, (T)37,5%

b) Spontaneous reactions are fast reactions; slow reactions cannot be spontaneous reactions (10)35%, (T)37,5%

c) Exothermic reactions are spontaneous reactions. (10)23%, (T)37,5%

More than half of the standard 8 students interpreted the phrase spontaneous reaction as a reaction that takes place without delay. This misconception was equally prevalent amongst standard 10 students. As the concept (thermodynamic) of spontaneous reaction is not formally considered at any level in the school syllabus the existence and persistence of misconceptions is not surprising. The everyday use of the word spontaneous is a probable source of misconception. This was noted in chapter 5. However explicit wrong statements also appear in school textbooks. For example, in a textbook used at a standard 8 level [35(f)]:

"The alkali metals lithium, sodium and potassium reacted very *energetically* (my italics) with water.....Reactions such as the above, which occur when two substances are brought into contact with each other *without first heating* them are called spontaneous reactions".

2.2 Research methods

1. Teachers movement towards the scientific view of reactivity.

Teacher understanding of and movement towards the scientific view of the concept reactivity was facilitated throughout the course.

Teachers were actively engaged during the course, in constructing their own knowledge during four sessions that spanned over a period four weeks and the pre-course work also spanning over a period of three to four weeks.

During the pre-course work the course participants had to elicit the from approximately 4-6 of their students their understanding of the concept reactivity.

Interview responses of these students, and teachers own responses during the pre-course work on experiments that were listed in the "Understanding Reactivity" pack, had to be brought for discussion during the first session.

The teachers' interaction with the pack, particularly during sessions 1,2,3 & 4 was facilitated, evaluated and supervised by the researcher in the role of course leader in an interactive manner during these sessions.

The course leader assisted the teachers to move gradually towards the scientific view about reactivity. This process was facilitated by the constructivist approach of the pack. The examples in the activity cards, were used to "anchor" and provide a "bridge", so that teachers moved towards constructing the scientific view of reactivity.

c) be aware that both exothermic and endothermic reactions can be spontaneous.

a) distinguish between the different approaches used experimentally for measuring reactivity;

b) differentiate between the everyday and scientific meanings of the terms reactivity and reactivity series.

2. Electrochemical series

By the end of the course teachers should be:

a) aware that voltage measurements do not give rate information;

b) aware that there is no necessary connection between cell emf (extent of a reaction) and the current (rate of the reaction).

3. Catalyst

By the end of the course teachers should be:

a) aware that a catalyst by *taking part* in the reaction offers an *alternative path* of lower activation energy;

4. Spontaneous reaction

By the end of the course teachers should:

a) differentiate between the everyday and scientific meanings of the term spontaneous;

b) recognise that speed of a reaction is not a criterion for a spontaneous reaction;

In view of the above the subjects selected for this study comprised two categories:

1. Teachers - Seven teachers from seven different schools who were currently teaching standard 8 students doing Physical Science.

2. Students - Standard 8 students of the schools above doing Physical Science.

In order to obtain the required information, it was decided to:

1. evaluate and ascertain the extent to which teachers have moved towards the scientific view about reactivity;

2. test standard 8 students of teachers who participated in the course;

3. test standard 8 students that were taught in a traditional way by teachers who did not participate in the course;

4. use test data previously reported for standard 8 students in the same or similar schools.

The specific content-related objectives that the "Understanding Reactivity" pack attempts to achieve are as follows:

1. Reactivity & reactivity series

By the end of the course teachers should be able to:

CHAPTER 2: AIMS AND STRATEGIES OF THE RESEARCH

2.1 Objective of Research

The traditional approach to teaching reactivity fails in drawing student attention to the fact that reactivity can be interpreted in a kinetic or a thermodynamic sense. Most school textbooks deal with reactivity in an ambiguous manner in this respect.

The different criteria used to measure reactivity are not explicitly addressed in most school textbooks. The concept of spontaneous reaction is not emphasized. Understanding of these concepts gained in standard 9 could form a springboard for the understanding of the more quantitative work done in rates of reaction and chemical equilibrium at a standard 10 level.

The aims of this study were:

1. to design a conceptual change course for individual science teachers from a number of schools, to develop their knowledge and understanding of *reactivity*;

2. to design an "Understanding Reactivity" pack according to the constructivist format, and use the pack in a conceptual change course for the teachers;

3. to ascertain the effectiveness of the ideas discussed with the teachers participating in the course to their standard 8 students.

the same standard 8 reactivity questionnaire as was used during phase I of the investigation.

1.3 Deliberating about the strategy and methodology for teaching reactivity

Teachers were also given an opportunity during the course to verbalise the aspects they would consider for drafting an outline of the teaching strategy, and the methodology they would use to transfer the newly acquired ideas to their students. From their responses the extent to which the individual teachers would apply the new strategies in the classroom and share the newly acquired ideas with their students was ascertained.

1.4 Testing the extent to which the concepts dealt with in the course material are transferred successfully to their standard 8 students by the participating teachers

Given that teachers had moved towards the scientific view of reactivity, does not necessarily imply that the newly acquired ideas will be successfully transferred to their students. Many factors may contribute towards unsuccessful transfer of knowledge. One of these factors, as indicated at the outset, is that no amount of instruction will be helpful to students if they are not determined to learn.

The extent to which the newly acquired ideas were transferred by the teachers who completed the conceptual change course was determined by the responses of the standard 8 pupils to the same standard 8

The new material in the pack does not detract from the concepts that are already currently in the standard 8 syllabus but attempts to show that the concepts can be linked in a complementary and meaningful way.

The design of the "Understanding Reactivity" pack was inspired by the constructivist strategy used by Summers[52,53] and his PSTS group. The "Understanding Reactivity" pack using a similar format attempts to link the concept of reactivity at the standard 8 level with topics which are traditionally dealt with only at the standard 10 level.

1.2 Facilitating a paradigm shift amongst participating teachers

Iser[46] indicates that the meaning of textual information is not derived wholly from reading the text but from the interaction of the reader with the textual information.

The researcher's teaching experience has shown that new material in itself is not sufficient. It has to be integrated in the learners cognition by a teacher who is familiar with the subject matter. An attempt was made to facilitate a paradigm shift amongst the course participants by the researcher in an interactive manner throughout the course. The researcher, as course leader was engaged in this process from the time the course material was introduced to the course participants to the time when the questionnaires were administered to their students.

CHAPTER 1: MODUS OPERANDI FOR PHASE 2

Phase 2 of this research as indicated previously, focused on improving the understanding of reactivity concepts by standard 8 teachers.

This phase specifically involved:

1. designing an "Understanding Reactivity" pack for use in a conceptual change course for teachers;
2. facilitating a paradigm shift amongst teachers participating in the course;
3. deliberating about the strategy and methodology for teaching reactivity;
4. testing the extent to which the concepts dealt with in the course material are transferred to their standard 8 students by the participating teachers in the course.

1.1 Designing an "Understanding Reactivity" pack for use in a conceptual change course for teachers.(APPENDIX O2)

Arising from previous findings, new material for secondary school teachers had to be designed, taking into account the difficulty with which learners accommodate and assimilate new material. The new material had to take into account teachers baseline of prior knowledge and employ a constructivist format to facilitate a paradigm shift amongst standard 8 science teachers towards correct conceptions.

Teachers views on aspects of reactivity were used to determine the starting point for designing the "Understanding Reactivity" pack.

PHASE 2

It is clear in this case that the students misconceptions do not lie with the methodology used by the teacher. The teacher merely plays a mediating role in transmitting incorrect ideas. The textbooks in fact may be playing the most important role in fostering misconceptions.

It would then follow that it is important that (i) instructional materials be designed and structured according to the constructivist format so that meaningful learning of the correct concepts takes place, (ii) teachers are offered in-service programmes that aim to bring about conceptual change.

Teachers understanding of the concepts to be taught have to be developed first as they are an important source of information students use to construct their concepts. This is the subject of phase 2 of the research.

CHAPTER 7: CONCLUSIONS FROM PHASE 1

This phase of the study has explored the views of students and teachers about several inter-related concepts: catalysis, spontaneous reaction, exothermic reaction, activation energy, reactivity, rate of reactions, equilibrium, reactivity series and electrochemical series.
It is evident that these are poorly differentiated and/or erroneously understood by students, teachers and textbook authors.

Teachers have been shown to have similar misconceptions to those of students. However the textbook is an important source of information not only for students but also for teachers. We have seen that the textbooks are poor guides to the understanding of these concepts. Therefore students are probably learning incorrect concepts from both teachers and textbooks.
Textbook authors organise their books along lines laid down by the syllabus. The syllabus does not link the concepts of reactivity, dealt with in standard 8, with those of rates of reaction and chemical equilibrium, dealt with in standard 10. Furthermore the standard 10 syllabus does not refer back to the concept of reactivity dealt with in standard 8. Textbook authors similarly fail to make such links.

In the light of the above it is inevitable that the standard 10 students have exactly the same misconceptions about reactivity as their standard 8 colleagues. Students are powerless to improve if their major sources of instruction - the teachers and textbooks - provide ambiguous and incorrect messages.

d) Reactivity series is invariant (Order of elements does not change)

Some teachers felt that the order of the elements in a reactivity series is invariant irrespective of the type of substance the elements react with.

"The order of the elements in the reactivity series does not change."

"I did not know how to explain why calcium is more reactive than magnesium with water but with oxygen it is less reactive than calcium."

The notions illustrated above by teachers are known, from research[8], to be also characteristic of pupil's views about reactivity.

4.2 Teachers responses during the discussion of the activity cards

The activity cards which contained anchoring and bridging examples indicated the extent of the awareness of the course participants of the material under discussion. Furthermore the cards also helped them to accommodate the new ideas and their movement towards the scientific view.

Activity cards 2 and 3 of session 2 contained descriptions of sporting events and chemical reactions respectively.

Teachers responses pertaining to the outcomes that were measured during each activity were elicited. These activity cards aimed at making the participants aware of the criterion used for judging reactivity in each case.

a) Methods used to measure reactivity unclear

Teachers were not clear as to what the experimental basis for measuring reactivity was. Some quotations to illustrate the above are given:

" The brilliance of the flame and the vigour of the reaction gives the reactivity".

" I am often confused as to how am I to measure the degree of reactivity, I usually let the results suit the demands of the author and syllabus".

b) Reactivity is considered anthropomorphically (Description uses human characteristics)

Some of the teachers had a human centered view of reactivity.

"Magnesium no matter how small gives a more *dramatic effect* than a larger piec of sodium."

"A metal is reactive if it reacts with vigour".

c) A spontaneous reaction linked to rate

Many teachers expressed the following views:

"A spontaneous reaction is a fast reaction".

"A spontaneous reaction takes place without delay"

"A non spontaneous reaction requires a catalyst"

course participants' own personal views about reactivity were considered while gaining insight into student's views about reactivity.

Card 1 - The reaction of metals with water.

Card 2 - The reaction of metals with oxygen.

Card 3 - The reaction of metals with aqueous solutions of metal salts.

Card 4 - The reaction of halogens with aqueous solutions of metal halides.

During each experiment similar focus questions were asked. Examples of the questions are:

1. "Which is the most reactive metal?"
2. "Which is the least reactive metal?"
3. "Give the order of the metals in terms of increasing reactivity with *elements or compounds concerned.*" (e.g. water, metal halides etc.)
4. "How did you arrive at the order in (3)?"

Certain features of teachers notions about reactivity became clear from their written and verbal responses. The responses below summarise the range of views expressed by the teachers. The views are similar to those expressed by pupils, during phase 1 of this investigations.

CHAPTER 4: EVALUATION OF TEACHERS UNDERSTANDING OF THE CONTENTS OF THE "UNDERSTANDING REACTIVITY" PACK

For the duration of the course, the course leader used a tape recorder to record the proceedings of the sessions. Teachers had indicated that they would not feel uncomfortable with this procedure and agreed with the course leader that the recordings could be "played back" where necessary to see if teachers views had changed.

Teachers understanding of reactivity-related concepts was assessed at various stages outlined below:

1. pre-course work
2. activity cards
3. homework questionnaire
4. draft outline of the teaching strategy
5. methodology for the implementation of design.

The draft outline of the teaching strategy and the methodology to be used for the teaching of reactivity are discussed in the next chapter.

4.1 Teachers ideas about reactivity elicited during pre-course work

During the pre-course work teachers' views were requested about reactivity in the experiments listed on the cards below. The teachers views had to be completed before interviewing pupils about their understanding of reactivity. The pre-course work was an important component of the "Understanding Reactivity" pack because

- Timing
- Running of the activity.

Aims of the pre-course work and the sessions

The aims of the pre-course work and each session are listed indicating the key aspects that are going to be addressed.

Resources to be provided by the course leader

The resources to be provided by the course leader for the pre-course work and each of the sessions are listed.

Timing

The total time and the duration for the discussion of the handouts during the pre-course work and each of the sessions is given.

Running of the activity

The actual procedure of implementation that is going to be used by the course leader during the pre-course work and sessions are elaborated on.

The pack contains details of the nature of the content under review.

The emphasis throughout the course is on the personal construction of knowledge by each teacher at a level that is appropriate for that individual.

The "Understanding Reactivity" pack has the following broad outlines:

- Outline plan of the course
- Summary of the course
- Activity cards.

Outline plan of the course

The pack at the outset gives an outline plan of the course indicating which key aspects are going to be dealt with during the pre-course work and the four sessions.

Summary of the course

A summary of the course describes the handouts that are going to be used during the pre-course work and the four sessions that follow. The summary also gives an indication of whether a handout will be followed by a discussion or a group activity and discussion, etc.

Activity cards

The number of activity cards that will be used for each session are listed.

For the pre-course work and each of the four sessions the following aspects are elaborated on:

- Aims of the pre-course work and the sessions
- Resources to be provided by the course leader

CHAPTER 3: OUTLINE OF THE "UNDERSTANDING REACTIVITY" PACK (APPENDIX 02)

The material in the pack has been designed according to the constructivist format to help secondary teachers develop their knowledge and understanding of reactivity and related concepts. It is different from other material in that it starts from ideas about reactivity that secondary school teachers already have and builds upon them.

The material is based on interviews conducted earlier with standard 8 pupils and on questionnaires administered to both teachers and pupils on reactivity-related concepts.

Approximately four sessions were used to introduce the concept of reactivity and related concepts and to emphasize the *rate* and *energy* viewpoints about reactivity.

The package highlights certain aspects of the scientific view of reactivity which are known from research to provide particular conceptual difficulties.

Course participants are introduced to the misconceptions which children and teachers possess and become aware of the nature of their own intuitive views. They are presented with the scientific interpretations of these situations and perform a series of practical activities designed to persuade them of their validity. More general accounts of the scientific view of reactivity are also presented again in terms of familiar everyday situations.

Teacher homework questionnaires

The "Understanding Reactivity" pack contained homework questionnaires based on " spot the expert view" which teachers had to respond to on completion of session 2 and 3. The responses to a questionnaire were discussed before the beginning of the subsequent sessions. The questionnaires contained statements that were scientifically correct as well as statements other than scientific. If the statement was scientifically correct the option "YES" had to be ringed and if the statement was scientifically incorrect the option "NO" had to be ringed.

Student questionnaire

A thirty minute reactivity multiple-choice type questionnaire used in the earlier investigation was used again to probe misconceptions of students at a standard 8 level on reactivity related concepts. Two additional open ended questions were included to complement the multiple-choice questions, and to support the reliability of the results.

The reactivity questionnaire was administered by the participants to standard 8 students, doing Physical Science. The questionnaire was administered subsequent to the completion of the teaching about reactivity, on a date decided by the participants and researcher. The reactivity questionnaires were delivered to the teachers that were taking part in the course. They were requested to handle the distribution and subsequent collection of the standard 8 questionnaires.

Details of the schools and teachers used are tabulated.

School + teacher	Standards taught by teachers	*Phase 1* No. of students	*Phase 2* No. of students of participating teachers	
			not delaying the teaching of reactivity	delaying the teaching of reactivity
1A	std. 8&10	-	40	-
2*B	std. 8&10	115	-	67
3C	std. 8	-	-	106
4*D	std. 8	48	-	166
5*E	std. 8&10	74	54	-
6F	std. 8&10	-	44	-
7G	std. 8&10	-	-	- 18
Total number of students		237	138	357

*The superscript (*) after a number indicates that the school took part in the phase 1 and phase 2 investigations. The notation 2*B implies school no. 2 took part in the phase 1 and phase 2 investigations and teacher B is currently teaching at the school.*

None of the teachers participating in the course took part in the earlier investigation.

Both teachers and students had to complete questionnaires.

2.3 Research design

During phase 2 of the investigation seven schools under the administration of the House of Delegates (H.O.D) were selected. Three of the seven schools indicated by an asterisk (*) had been involved in the earlier investigation(phase 1). The teachers from the following schools were selected: Lenasia South Secondary, Lenasia Secondary, Himalaya Secondary, Laudium Secondary, Azadville Secondary, Topaz Secondary and Laudium Islamic Secondary. These schools were selected because they were fairly representative with respect to academic standards. Teachers, schools and number of students used in this (phase 2) and the earlier (phase 1) investigations are shown in the table that follows. Teachers that volunteered to participate used 4-6 students during the pre-course work to elicit the students understanding of reactivity. Four of the seven teachers delayed the teaching of reactivity.

Three teachers had already started the teaching of reactivity in April. Their teaching of reactivity was running parallel to, or ahead of the course that was presented and therefore it was considered that they did not delay the teaching of reactivity. Students were expected to be taught in a traditional. These teachers were allowed to participate and contribute towards the discussions during the course.

Time table indicating the progression of events from implementation of the course material to administering the std.8 questionnaire.

MONTH	WEEK BEGINNING	DURATION	TASK
March	14/3	1hr 45min	Pre-course work
	21/3	-	Pre-course work
	28/3	-	Pre-course work
April	11/4	1hr 45min	Session 1
	18/4	1hr 45min	Session 2
	25/4	1hr 55min	Session 3
May	2/5	0hr 30min	Session 4
		1hr	Session 4: Aspects to consider-for draft outline of teaching design.
	16/5	-	Busy designing teaching strategy
	23/5	-	Busy designing teaching strategy
	30/5	1hr 55min	Session 5: Discussion first draft outline of teaching strategy
June	6/6	3 weeks	Busy refining teaching strategy
	13/6		Busy refining teaching strategy
	20/6		Busy refining teaching strategy
	27/6		Session 6: Draft outline of teaching strategy finalised.
July	4/7		School vacation
August	1/8	3 weeks	Teaching design to be implemented
	8/8		Teaching design to be implemented
	15/8		Teaching design to be implemented
	22/8		Feedback of implementation
	29/8	30 min.	Questionnaire administered

Interaction between the course leader and the teachers continued for the entire duration of the course.

2. Teaching the topic reactivity

Part of session 4, and sessions 5 and 6 were used to elicit from the teachers verbally and in written form the teaching strategy and the methodology they would use to transfer the newly acquired knowledge to their pupils.

3. Implementation of the instructional strategy

On completion of the course material and drafting of the outline and methodology to be used for teaching the concept reactivity, the teachers had to teach the topic reactivity to their standard 8 students. This phase spanned over a period of approximately four weeks and was not directly observed by the researcher.

4. Students understanding of reactivity

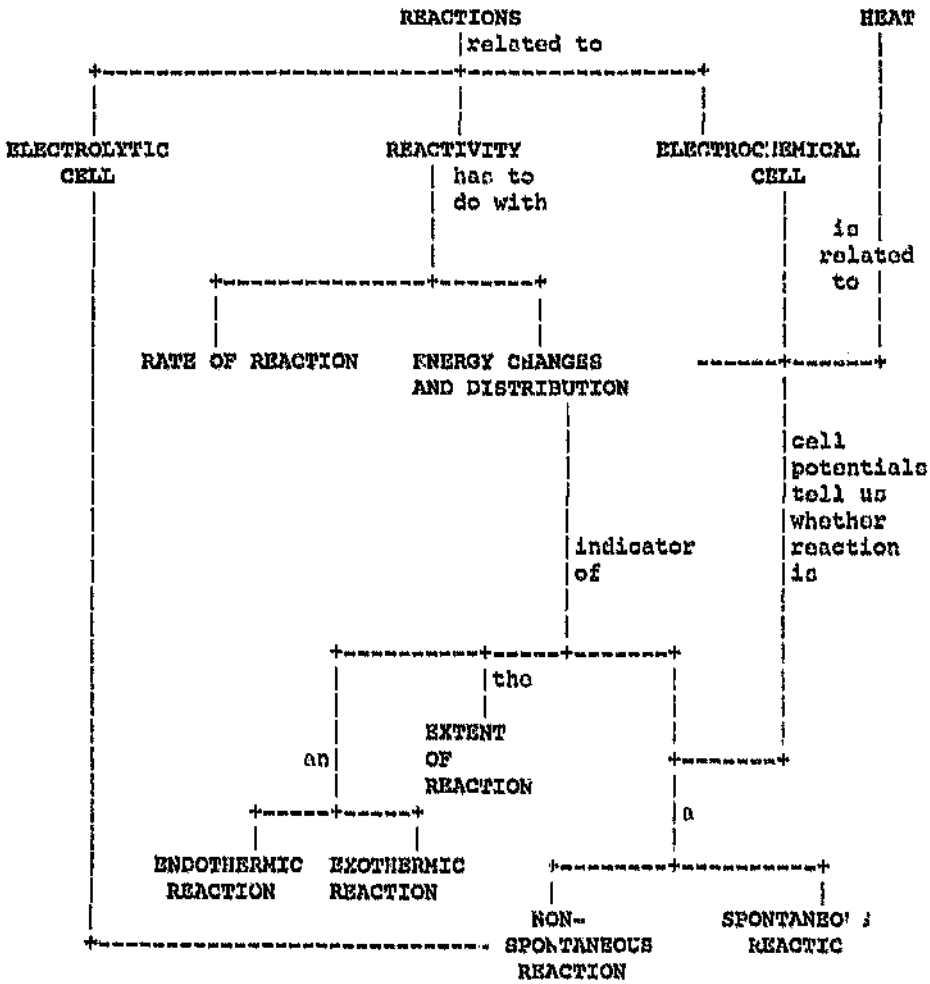
Student understanding of reactivity- related concepts was tested after receiving instruction, using a reactivity multiple-choice type questionnaire. The questionnaire contained a combination of multiple-choice and open ended questions in a complementary manner. The multiple-choice questions were identical to those used in phase 1 of the investigation.

The four stages described above spanned over a period of six months. A summary of the programme is tabulated.

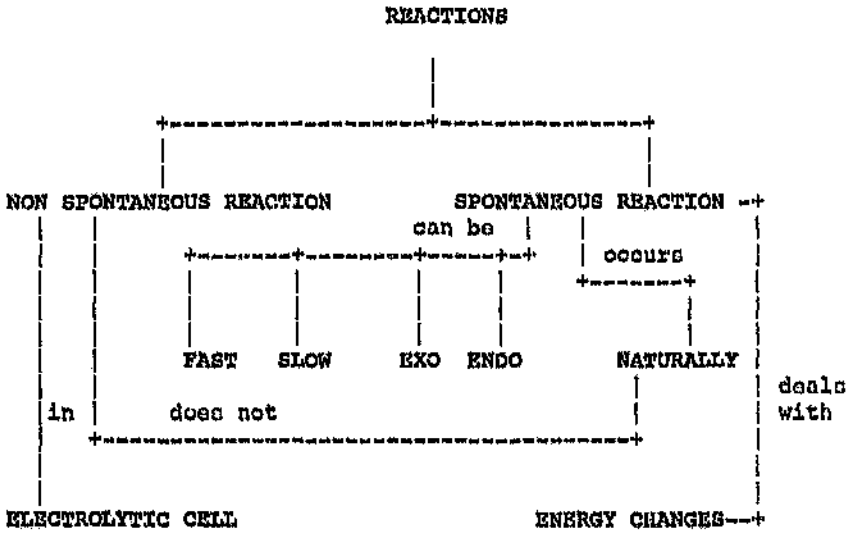
Suggested outline no. 3.

DESIGNING THE TEACHING MATERIAL ON REACTIVITY

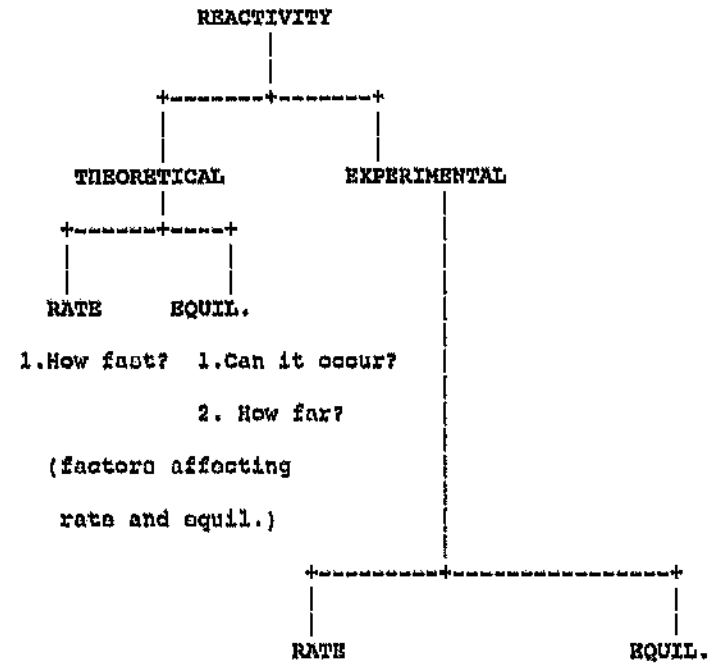
ADVANCE ORGANISER



Suggested outline no. 2.



Suggested outline no. 1.



1. Can students distinguish experimental approaches to measure reactivity?

Teachers: "I have never thought that I could relate electrolytic cells to reactivity and to spontaneity"

Teacher(s): "Heat can be related to the energy changes in chemical reactions-I never used to relate the physics to chemistry".

Teacher: "My teaching was so compartmentalised"

Course leader: "In my earlier teaching I also did not relate the section on heat to energy changes that take part in a chemical reaction."

Course leader: "Do you think that you have been benefiting from the course."

Teachers: Yes, the discussions are very helpful.

Course leader: "If I run a similarly structured course on Vectors, do you think teachers will be interested?"

Teachers: "Definitely."

The course leader got the feeling that the participants had only referred cursorily to the syllabus in the past and this endeavour was helpful.

It was suggested by the course leader that outline 3 could perhaps serve as an advance organiser for linking related concepts more meaningfully. It was also spontaneously adopted by the teachers that the outline would be helpful for sequencing and adapting their teaching material, preferably to a constructivist format to make students learning more meaningful.

Course leader: You have to go through the syllabus and see how these concepts can be linked. Once you have a picture you must design a teaching strategy to teach the concepts related to reactivity.

The teachers abilities to synthesize and apply the new information was elicited. They were requested to outline diagrammatically the links between the reactivity-related concepts in a meaningful way. These outlines had to be brought to session 5.

Some of the draft outlines brought by teachers during session 5 are shown to indicate how they had linked the concepts. Draft outlines 1 & 2 drawn up as homework by two of the teachers have been included.

Outline 3 was constructed during session 5, using the standard 8 syllabus, in a cooperative and supervised manner by the teachers and the course leader. Outline 3 indicates and highlights some of the links of related concepts that can lead to meaningful learning. Some of the views expressed by the teachers and course leader after constructing this outline are quoted:

Course leader: "If you have a global idea of what you are attempting to do, it is very helpful. Sometimes the global picture needs to be given to the students beforehand".

Teacher :"I have never looked at reactivity in this way.... so many concepts can be linked"

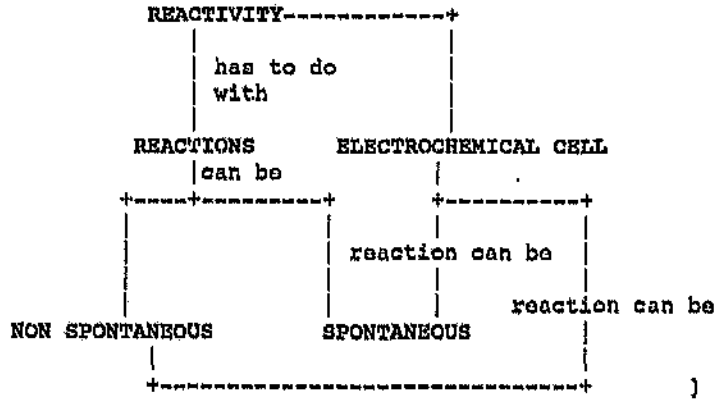
Teacher(s): Yes, we can.

Course leader: What about electrochemical cells. Do you think this can be linked to reactivity?

Teacher(s): Yes, chemical energy is converted to electrical energy.

Course leader: I have drawn your attention to several concepts, lets see how you can link them. I will give you an example.

(Course leader draws the following flow diagram on the chalkboard:



)

Course leader: I have linked the concepts using linking words. Reactivity can be linked to non spontaneous and spontaneous reactions. Electrochemical cell can be linked to the concepts of spontaneous and non spontaneous reaction.

Course leader: In 2.8.3 one is dealing with electrochemical cells: this concept is dealt with at a matric level. If you remember cell voltages tell us nothing about rate. This is another method for measuring reactivity.

Course leader: Working within the scope of the syllabus, and what we have done, lets see how these concepts can be linked by means of a flowchart.

Course leader: While going through the course material we have expressed a need to present the material in the syllabus in a different and more coherent way.

Course leader: Lets look at the extent to which the knowledge acquired during the course could be integrated with related topics in the syllabus.

Course leader: Do you think that we can perhaps link electrolytic cells to the concept of reactivity?

Teacher: No I don't think so.

Course leader: Do you think that the reactions in an electrolytic cell are spontaneous or non spontaneous?

Teacher: Spontaneous.

Course leader: Why?

Teacher: Because the reaction is taking place.

Course leader. Yes, but energy is continuously supplied.

Course leader: Ok, so if the reaction in an electrolytic cell is non spontaneous can we not link this to reactivity?

Course leader: You will notice that 2.5.1.2 refers to the rate aspect of reactivity. A method which can be used to measure reactivity.

Excerpt from syllabus

[2.5.1.3 Reactions with solutions of metal salts.

.....in some cases an increase of temperature is detectable. This indicates a release of energy.]

Course leader: You will notice that 2.5.1.3 refers to the energy aspect of reactivity. Another method for measuring reactivity.

Excerpt from syllabus

[2.8 Chemical reactions and electricity.

2.8.2 Electrolysis

Comparison of the electrolysis of $HgCl_2$, or $CuCl_2$ with the decomposition of HgO when heated. In both cases a compound decomposes as a result of an addition of energy].

Course leader: You will notice that 2.8.2 refers to endothermic reactions: energy can be absorbed in different ways.

Excerpt from syllabus

[2.8.3 Reactions producing electrical energy.

Demonstration of the establishment of a potential difference between the electrodes of a simple cell. Transformation of chemical energy into electrical energy].

Course leader: Please bring your draft attempts of the outlines linking reactivity to related concepts for discussion during session 5.

Course leader: I will give you an example later, of the type of linkage I am referring to.

Course leader: Let's see where these concepts on the chalkboard appear in the syllabus so that we can link key concepts meaningfully when you teach reactivity.

Excerpts fr «m the syllabus relevant to the course material had been reproduced to complement the comments that follow. The numbering of the syllabus was retained for cross referencing purposes. The teachers attention was drawn to the location of those concepts in the syllabus. The descriptions that were not part of the dialogue are put in square brackets.

Excerpt from syllabus

[2.5 Attention should be drawn to the fact that some reactions take place spontaneously and others do not.
2.5.1.1 Reactions of metals]

Course leader: If you look at 2.5 of the syllabus, you will notice that spontaneity was dealt with during our course.

Excerpt from syllabus

[2.5.1.2 Reactions with water
.....noting the rate at which these elements release hydrogen]

CHAPTER 5. TEACHING STRATEGY AND METHODOLOGY TO BE USED WHEN TEACHING REACTIVITY

After going through the course material for session 4, teachers responses about how the newly acquired material should be taught were elicited. Their attempts were supervised and directed during the remaining sessions, on aspects indicated below:

-diagrammatic outline, linking key reactivity-related concepts
-teaching strategy for the topic reactivity
-methodology to be used for teaching reactivity.

5.1 Diagrammatic outline linking key reactivity-related concepts

Teachers were given a copy of the relevant sections of the standard 8 Physical Science syllabus (appendix C1). The following comments were made by the course leader and the teachers participating:

Course leader: We have gone through the course material, let's list the concepts we dealt with, I am going to write some of them on the chalkboard.

The teachers attention was drawn by the course leader to the following concepts that were discussed during the course. These were listed on the chalkboard:

-Spontaneous reaction
-Reactions that absorb energy
-Reactions that give off energy
-Reaction of metals
-Electrolytic cell
-Electrochemical cell

extent to which teachers had moved towards the scientific view.

The goal of the homework exercises was to introduce the teachers to a range of views about the concept reactivity as related to chemical reactions like those they had already met, including "expert" or "scientific" explanations.

The homework questionnaire contains several situations similar to those which the teachers encountered during their pre-course enquiry.

The teachers task was to "spot the expert view(s)" among the statements about each situation.

The completed questionnaire was discussed before commencing of a new session.

The large pr·entage of correct responses by each teacher to the homework questionnaire ind;cated that the contents of the pack had been understood and that teachers had moved towards the scientific view about reactivity.

The following response encompasses the views expressed by most of the teachers when going through activity cards 2 and 3 of session 2.

"It depends what you are measuring. Do you want to know how far or how fast?"

Implicit in this response was that which was being ascertained in the pre-course work:

What was the basis for measuring reactivity in the pre-course work? Was it how fast or was it how far?

Activity cards 2, 3, 4 and 5 of session 3 contained descriptions of spontaneous reactions. Some of the more representative teacher responses are illustrated:

" I always thought that spontaneous reactions has to do with speed"

" I see, spontaneous does not mean instantaneous"

" Oh, spontaneous processes has to do with energy changes"

The above responses indicated movement towards the scientific view.

The participants indicated that the discussion on the activity cards were very meaningful since the process of understanding was facilitated by the course leader.

4.3 Teachers responses to the homework questionnaire

The homework questionnaires were used by both the teachers and the course leader as indicators to assess teacher understanding of the

Teaching delayed (old schools; N=233) with teaching undelayed (old schools; N=54). (Appendix D2)

A students t-test showed that the average percentages obtained by these two categories of students in phase 2 on the questionnaire were significantly different. The one category of students received delayed teaching of reactivity and the other received undelayed teaching.

Teaching delayed (N=233): 33%

Teaching undelayed (N=54): 25%

Teaching undelayed (old schools; N=54) with teaching undelayed (new schools; N=84). (Appendix E2)

A students t-test showed that average percentages obtained by the two categories of students in phase 2 on the questionnaire were not significantly different. Both the categories of students did not receive delayed teaching of reactivity.

Teaching undelayed (N=54): 25%

Teaching undelayed (N=84): 25%

Teaching delayed (old schools; N=233) with teaching delayed, (new schools; N=124). (Appendix F2)

A students t-test showed that average percentages obtained by the two categories of students on the questionnaire were significantly different. The one category of students received delayed teaching of reactivity and the other received undelayed teaching.

Teaching delayed (N=233): 33%

A Chi squared test for independence indicated that there was a significance difference for the following questions:

question 5 (N=138) did better;

question 6 (N=411) did better.

There was no significant difference for questions 1,2,3,4,7 & 8.

Teaching delayed, (old & new schools; N=357) with teaching undelayed, (old & new schools; N=138). (Appendix C2)

A students t-test showed that the average percentages obtained by the two categories of students in phase 2 on the questionnaire were significantly different. One category delayed the teaching of reactivity and the other did not.

Teaching delayed (N=357): 29%

Teaching undelayed (N=138): 25%

A Chi square test for independence indicated that there was a significant difference for the questions

question 3 & 4: (N=357) did better.

There was no significant difference for questions 1,2,5,6,7 & 8.

(The level of significance is taken to be $\alpha = 0.05$ or the 5% significance level.)

For question 1 the probability of getting a value of X^2 as large as calculated is 0.660. Since Probability > 0.05, H_0 is not rejected and we conclude that the groups are not different in their responses at $\alpha = 0.05$.

A similar conclusion holds also for questions 2,7, and 8.

For question 3, the probability of getting a value of X^2 as large as calculated is 0.00.

Since Probability < 0.05, H_0 is rejected and we conclude that the populations are different in their responses for this question.

A similar conclusion holds for questions 4, 5 and 6. In all questions (3,4,5 and 6) where there is a significant difference, the, phase 2 delayed group of students performed better than the phase 1 group of students.

Phase 1,(N=411) with teaching undelayed phase 2, (N=138).

(Appendix B2)

A students t-test showed that the average percentages obtained by the two categories of students on the questionnaire were not significantly different.

Phase 1 (N=411): 25%

Phase 2 undelayed (N=138): 24%

The probability of getting a t-value as large as 4.5362 if H_0 is true is 0.0000. Therefore H_0 is rejected and we conclude there is a significant difference between the means of both groups at α =0.05. (standard 8(N=411) mean = 24%, standard 8(N=357) mean = 29%). The phase 2 delayed group did better than the phase 1 group.

The average percent choices by these students for the correct responses and the accompanying options for each multiple-choice question of the reactivity questionnaire are given later.

For the purposes of the comparison the responses for the multiple-choice questions were treated as either 0(wrong) or 1(correct) i.e the resulting data is not normally distributed. A X^2 test was then employed to compare the results of the phase 1 group to the phase 2 delayed group for the reactivity questionnaire.

A Chi square test for independence was carried out to determine whether or not the correct/wrong response is independent of whether standard 8 students are from phase 1 group (N=411) or phase 2 delayed group (N=357).

The following null hypothesis H_0 and alternate hypotheses H_1 are assumed.

H_0: The response is independent of group.
H_1: The response is not independent of group

4. Comparison of results for schools that took part in phases 1 & 2 on the reactivity questionnaire. (Appendix I2)

5. Individual student responses of both the phase 2 delayed groups and undelayed groups to the reactivity questionnaire. (Appendix J2)

6. Histograms. (Appendix K2)

   6.1 Comparison of standard 8 results, per question for phase 1 (teaching undelayed) with phase 2(teaching delayed) on the reactivity questionnaire.

Phase 1,(N=411) with teaching delayed phase 2, (N=357).(Appendix A2)

A Students t-test was employed to compare the overall average obtained by the standard 8 students of both groups for the reactivity questionnaire.

The following null hypothesis H_0 and alternate hypothesis H_1 are assumed.

H_0: The mean responses for groups (N=411) and (N=357) are equal.
$\{u_8(N=411) = u_8(N=357)\}$

H_1: The mean responses for groups (N=411) and (N=357) are not equal.
$\{u_8(N=411) \neq u_8(N=357)\}$

(The level of significance is taken to be $\alpha = 0.05$ or the 5% significance level)

Results

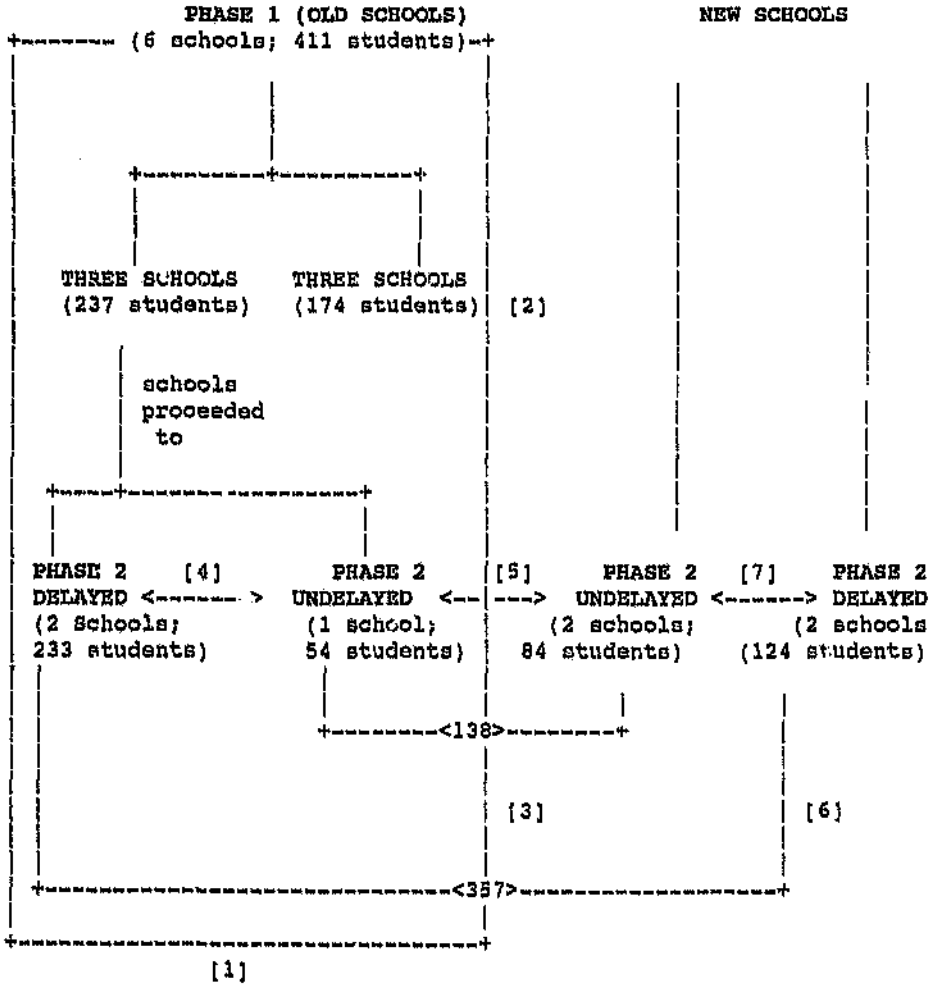
The results of the following analyses are given in the appendixes as shown below. The numbers in the square brackets [ ], also appear in the diagram above to aid in tracking the comparisons. (Refer to diagram)

1. Comparison of standard 8's results for phase 1 and phase 2 on the reactivity questionnaire:
   1.1 [1] Phase 1,(N=411) with teaching delayed phase 2, (N=357). (Appendix A2)
   1.2 [2] Phase 1,(N=411) with teaching undelayed phase 2, N=138). (Appendix B2)

2. Comparison of standard 8's results for phase 2 on the reactivity questionnaire:
   2.1 [3] Teaching delayed, (old & new schools; N=357) with teaching undelayed, (old and new schools; N=138). (Appendix C2)
   2.2 [4] Teaching delayed (old schools; N=233) with teaching undelayed (old school; N=54). (Appendix D2)
   2.3 [5] Teaching undelayed (old school; N=54) with teaching undelayed (new schools; N=84). (Appendix E2)
   2.4 [6] Teaching delayed (old schools; N=233) with teaching delayed, (new schools; N=124). (Appendix F2)
   2.5 [7] Teaching undelayed, (new schools; N=84) with teaching delayed, (new schools; N=124). (Appendix G2)

3. Comparison of different schools results for phase 2 on the reactivity questionnaire. (Appendix H2)

A schematic diagram indicating the number of schools and students that participated during phase 1 and 2 of the investigation is given below. Six schools participated in phase 1 of the investigation. Three of the six schools proceeded to participate in phase 2 of the investigation. Four new schools participated in phase 2 of the investigation. Some schools during this phase delayed the teaching of reactivity and others did not.



CHAPTER 6: REACTIVITY QUESTIONNAIRE - CONTENTS AND GENERAL OUTCOMES

The general outcomes from use of the standard 8 questionnaire in phase 2 are described.

The original reactivity questionnaire contained only multiple-choice questions. As described under the investigations of phase 1 these questions was designed to ascertain students understanding of the concepts reactivity, reactivity series and related concepts tested earlier in the interviews. During phase 2 of the investigation two additional open ended questions about reactivity were included in the standard 8 questionnaire. The open-ended questions attempt to compare the standard 8 phase 2 groups responses to those that were given by standard 10 students during phase 1.

The distractors used for the multiple-choice questions referred to possible misconceptions. The concepts tested by the questions were within the framework of the topics of rates of reaction and chemical equilibrium. The distractors for the questions on reactivity series had a "rate bias", i.e. they frequently invoked a connection between rate of reaction and reactivity. Hardly any distractors were related to the overall energetics (equilibrium) of the reaction. Options such as "none of the above" were included so that, if students felt that the options which were given did not relate to either the kinetic or the thermodynamic implications in the term reactivity, they could choose these options.

concepts. Furthermore practical work should form an integral part of the teaching and learning of the concept reactivity.
Their views were consistent with what has been cited in research. Research considered hands on practical work to be important for learners in order to:

-facilitate concept formation
-enhance insight and understanding.

Time allotted for teaching reactivity:
Teachers indicated that approximately three to four weeks were required for teaching the topic "Reactivity". The total number of periods that they would allocate to the teaching of the topic would be approximately 20 to 24 periods, each period of 35 minute duration.

The teachers efforts during these sessions were encouraging and indicated that much thought had been given to considering what would make learning by pupils more meaningful.

(4) State what the term reactivity means.

(5) Be familiar with the various approaches used to measure reactivity.

(6) Distinguish questions of rate from questions of equilibrium.

5.3 Methodology to be used when implementing teaching strategy

Apart from having a logical sequence, the number of periods and how the transfer of the newly acquired knowledge is going to be realised was also discussed.

Teachers views of the approach they were going to use to get the message across to their standard 8 pupils were elicited.

Some notions expressed by teachers:

Course leader: "What type of approach will you use to get your message across? Would you use the narrative approach?"

Teacher(s): " Definitely not, practical work is important"

Course leader: "But during the pre-course work, you used practicals. That did not seem to be helpful"

Teacher: No, no I don't think so, you must become aware of what you observing."

Teacher(s): "Theory and practical work must go hand in hand."

Practical work:

The above quotations by teachers, indicated that they felt that practical work was an important component for understanding science

The views above were considered by teachers to be important when drafting a teaching design. These views are consistent with that which is currently prevalent amongst the science educational community.

Objectives:

McConki[47] and Shepardson and Pizzini[42] indicate that the purpose for learning directs the attention to the selection of textual information. Different purposes for learning influence attention differently and thus the selection of textual information. It would appear that the stipulation of objectives at the beginning of a topic or new concept may focus a students attention in a desired direction.

This aspect was considered when the "Understanding Reactivity" pack was designed. Each session in the pack was preceded by a statement of objectives of the particular session.

Similar views as those above were expressed by the teachers. Teachers indicated that students attention should be drawn to the objectives of the lesson.

Some objectives formulated by the teachers and the researcher arising from the discussion are listed below.

After careful study of this unit you should be able to:

(1) State the criteria for the direction of spontaneous chan_ .

(2) Recognise an exothermic reaction by using a thermometer.

(3) Recognise an endothermic reaction by using a thermometer.

5.2 Teaching strategy for the topic reactivity

During session 5 the strategy for teaching reactivity and the methodology they would use to transfer the acquired knowledge was also elicited.

The notions expressed by most teachers indicated that the following aspects were important when considering the teaching design:

-objectives
-previous relevant knowledge
-language usage.

Notions expressed by teachers during the discussion:

Some of the more representative notions expressed by the teachers and falling within the categories mentioned above are quoted:

Objectives

"I will try to structure like you have done in the pack, give the aims of the lesson".

Previous relevant knowledge

"Do not assume prior knowledge - try to find the starting point for the children".

"I would like to start with pre-course work and move from there".

Language usage

"I will try to distinguish the scientific meaning from the everyday meaning. For instance spontaneous does not mean instantaneous".

Discussion.

That the overall reaction is exothermic (option A) is correctly reflected by 17-20% more students of the phase 2 delayed group as compared to the other groups.

A Chi square test indicated that the result 57% correct, is significantly better than the 37% correct for phase 1.

Perhaps this indicates that the students of the phase 2 delayed group are aware that an exothermic reaction is one that is indicated by a rise in temperature and an endothermic reaction by a drop in temperature.

Identifying an exothermic and an endothermic reaction was dealt with in activity cards 3 and 4 respectively during session 3 and the concepts elaborated further by the course leader.

Options B + D + E all focus on pre-heating. All these attach more importance to this, than the subsequent exothermic reaction. The total number of students in the phase 2 groups who chose these options decreased by 16-20%, as compared to phase 1, suggesting there was a better understanding of the purpose of heating the sodium. For the phase 2 delayed group this matches the increase in option A,(the correct choice), whereas for the phase 2 undelayed group it matches the increase in option C (another incorrect choice).

Question 4.

Objective: To test whether students can distinguish between exothermic and endothermic reactions.

Question 4

When Na is heated in a deflagrating spoon, and then inserted in a gas jar of oxygen, there is a vigorous reaction with oxygen accompanied by the emission of light. The reaction of Na with *oxygen* can be considered to be

	Options	Phase 1 %/option	Phase 2 /%option Undelayed	Delayed
-	No response	0,7	1.4	0.0
#A.	exothermic because energy is *liberated* in the form of light.	37,4	39.1	56.6
B.	endothermic because Na was *heated before* the reaction could take place.	23,2	13	11.5
C.	spontaneous because the reaction was *rapid*.	13,4	27.5	15.1
D.	non spontaneous because Na had to be heated.	11,0	11.6	9.0
E.	catalysed because the *heat supplied* was a catalyst for the reaction.	14,2	7.2	7.0

By this term, sudden movement or instantaneous is also implied.

About 25% of the students still felt that a spontaneous reaction takes place without heating.
This may be reflecting the same basic view, namely that it takes place without delay.

17-20% more students in the phase 2 delayed group, as compared to both the other groups chose the scientifically correct option E.
This indicates perhaps, a better presentation by the teachers, who participated in the course and had moved towards the scientific view of the concept spontaneity.

A Chi square test indicated that the 27% correct by the phase 2 delayed group is significantly better than the 11% by the phase 1 group. The concept of spontaneity was intensively and extensively dealt with during session 3 of the pack.
The encouraging shift in the responses of the students indicates that the activity cards used with the teachers during session 3 were helpful to them in moving their students towards the scientific view.

The percentage correct response by the students in the phase 2 undelayed group was comparable to that of phase 1. It therefore seems that the teaching of t e concept was not being influenced by the fact that the teacher was participating in the course.

Question 3.

Objective: To test students perception of the concept spontaneous reaction.

Question 3

A spontaneous reaction is a reaction that

	Options	Phase 1	Phase 2/%option	
		%/option	Undelayed	Delayed
-	No response	-		-
A.	always gives off energy.	7,8	2.9	7.0
B.	always absorbs energy.	2,4	4.3	4.2
C.	takes place without any delay.	58,4	66.7	36.4
D.	occurs without heating it.	20,4	18.8	24.9
#E.	can occur, however it could be fast or slow.	10,9	7.2	27.5

Discussion.

Option (C) was once again the most popular response for all groups. However about 22-30% fewer students in the phase 2 delayed group, as compared to the other groups, chose this option. This indicates that fewer perceive a spontaneous reaction as one that takes place without any delay.

Those students that still have a misunderstanding of the term spontaneous are probably still influenced by it's everyday usage. The term is probably understood to imply that the act is voluntary or taking place at it's own accord and without external incitement.

Discussion.

The percentage responses by students remained approximately the same for all three groups.

A fairly large percentage of all three groups chose the correct option (B). This answer was an obvious choice, and it is surprising that not more than 62% chose it.

The choice of options (A) and (D), totaling about 25% of all three groups of students, indicates a belief that the relative speed with which the metals react can be deduced from the reactivity series. Choice A is probably a relatively strong distractor as many students have seen the reactions concerned.

The pack emphasizes during session 2 that both kinetic and thermodynamic considerations are implicit in the term reactivity. However the correct choice does not require any distinction between these. Hence the lack of influence of the pack on the outcome is expected.

Question 2.

Objective: To ascertain students interpretation of the reactivity series.

Question 2

The following statements are given below:

Use the accompanying reactivity series for metals and hence choose the *most* appropriate response:

	Options	Phase 1	Phase 2/%option	
		%/option	Undelayed	Delayed
-	No response	0,7	2.9	0.6
A	K reacts *faster* with oxygen than Na does.	15,9	13	15.0
#B.	The least reactive metal is Au.	65,9	65.9	62.7
C.	K will react with *more* oxygen than Na.	3,7	4.3	2.8
D.	the reactivity series can be used to predict which metal would react the fastest with sulphur.	7,3	5.8	9.0
E.	None of the above statements is correct.	6,6	8.0	9.0

also of an alternative pathway to reach the final destination is missed.

The same standard 8 textbook[35] used by students in both phases of the investigation transmits this misconception. The textbook states that "a catalyst speeds up the rate of a reaction without participating in the reaction". A large percentage of the students in standard eight used this textbook as a major source of instruction.

The "Understanding Reactivity" pack dealt only cursorily with the concept of a catalyst. This concept is not formally in the standard 8 syllabus. The continued prevalence of misconceptions about a catalyst is to be expected in the absence of *activity card(s)*, in the "pack" attempting to remedy the misconception.

Teachers indicated that the concept of a catalyst was not emphasized in their teaching precisely because it is not in the syllabus. Against this background the students responses are understandable.

Question 1

Objective: To test students understanding of the term catalyst.

Question. 1

I. A catalyst speeds up the *rate* of the reaction without taking part in the reaction.

II. A catalyst increases the *yield* of the products in a reaction.

III. A catalyst *initiates* a reaction.

IV. A catalyst increases the rate of the reaction.

Which of the above statements do you consider to be definitely appropriate?

# indicates correct response

	Options	Phase 1	Phase 2 /%option	
		%/Option	Undelayed	Delayed
-	No response	-		-
A.	I	78,8	80	84.0
B.	II	1,5	0.7	0.0
C.	III	2,7	1.4	0.6
#D	IV	7,5	7.2	8.4
E	III & IV	9,5	10.1	7.0

Discussion.

The results of this question confirms that there is cause for concern.

Approximately 80% of each group of the standard 8 students believed that a catalyst speeds up a reaction without taking part in the reaction. The idea of regeneration as the reaction proceeds and

Students were directed to use the following reactivity series in the questions unless otherwise stated. This reactivity series has been taken from a standard 8 Physical Science textbook without any modification.

Reactivity series for metals

K

Ba

Ca

Na

Mg

Al

Zn

Fe

Pb

(H)

Cu

Hg

Ag

Au

CHAPTER 7: REACTIVITY QUESTIONNAIRE - ANALYSIS OF RESPONSES

Responses for the multiple choice questions during phase 2 by the teaching delayed (N=357) and the undelayed (N=138) groups are considered. The responses by the teaching delayed group (N=357) for the open-ended questions are also given.

Responses for the multiple-choice questions made by standard 8 students (N=411) during phase 1 have been reproduced for comparison purposes.

7.1 Analysis of response to the reactivity questionnaire

The standard 8 questionnaire appears in Appendix A.
The standard 8 students were presented with a variety of questions which aimed to test their understanding of reactivity and related concepts. In this section, the responses of the students in this and an earlier investigation are discussed on a question-by-question basis.

Students were presented with eight multiple-choice questions and two open-ended questions. In the former case the response previously identified as correct is marked with an #, and the percentage of students from the respective groups selecting each response is indicated for each question.

The means for the schools involved were respectively:

school 2(phase 1) = 23%;

school 2(phase 2; delayed) = 35%

school 4(phase 1) = 19%;

school 4(phase 2; delayed) = 32%

school 5(phase 1) = 35%

school 5(phase 2; undelayed) = 25%).

Individual student responses for phase 2 groups to the reactivity questionnaire. (Appendix J2)

The total mark obtained for the questionnaire by each student of phase 2 is given.

Histograms. (Appendix K2)

- Histogram showing a comparison of standard 8 results per question for phase 1 (teaching undelayed) with phase 2 (teaching delayed) on standard 8 questionnaire.

- Histogram comparing schools that participated in both phase 1 and 2.

The responses to the questionnaire are dealt with in more detail in the next chapter.

Teaching delayed (N=124): 21%

Teaching undelayed, (new schools; N=84) with teaching delayed,(new schools; N=124). (Appendix G2)

A students t-test showed that average percentages obtained by the two categories of students on the questionnaire were not significantly different. One category received delayed teaching of reactivity and the received undelayed teaching.

Teaching undelayed (N=84): 25%

Teaching delayed (N=124): 21%

Comparison of different schools results for phase 2 on the reactivity questionnaire. (Appendix H2)

The performance of the standard 8 students of phase 2 of each of the four schools that delayed the teaching of reactivity for the standard 8 questionnaire is given. The average performance at all the schools was poor. School number 2 and 4 results were respectively 35% and 32% . These schools did significantly better than school numbers 3 and 7, the average scores obtained being 22%, and 22% respectively.

Comparison of schools results that took part in pnase 1 and 2 of investigation on the reactivity questionnaire. (Appendix I2)

Three of the schools of phase 2 also took part in the investigations during phase 1. These schools delayed the teaching of reactivity. Two out of the three schools did significantly better during phase 2 as compared to phase 1 whilst one did significantly worse.

partial success. This is not reflected however in an increase in the percentage choosing the correct response. Rather there was an increase in the percentage opting for another common misconception.

4. There is evidence that teachers in the phase 2 undelayed group, were influenced by the course and transferred some of this influence to their students, as the course proceeded.

In the light of the observations it was decided to make further comparisons of overall outcomes on the following basis:

1. Question 1,2 and 6 would be omitted from the analysis
2. The best answer to question 7 should be made E.
3. In question 8, options A, E and B should all be regarded as appropriate in order to give credit to students who did *not* choose option D.

Alternative analysis of outcome

Alternative comparison of the phase 2 delayed and undelayed groups on the reactivity questionnaire. (Appendix L2)

A students t-test on the overall percentages achieved by the two phase 2 groups showed the phase 2 delayed group performed significantly better than the phase 2 undelayed group:

Phase 2 delayed group - 41%

Phase 2 undelayed group - 32%

7.2 Review and alternative analysis of response to the reactivity questionnaire

Reviewing the questionnaire on a question by question basis shows mixed outcomes from students in relation to the intervention with the teachers. To get a fair assessment of what the intervention may have achieved a number of general points can be made:

1. Some questions are not suitable for detecting any influence of the course.

   Question 1 dealt with the concept of a catalyst and was not formally in the standard 8 syllabus.

   Question 2 could be answered correctly without a proper understanding of the reactivity concept.

   Question 6 could not be answered correctly by a student who did have a proper understanding of the reactivity concept.

2. The most appropriate response to certain questions may not be as previously thought.

   In question 7, the most appropriate response in terms of the understanding the course aimed to develop is option E, rather than option C the option previously identified as most appropriate.

3. The response to the question before and after intervention indicate partial improvement in that one basic misconception seems to have been alleviated. However the correct response was still not made.

   In question 8, the marked decrease in the percentage believing that there is only one reactivity series is an indication of

Discussion.

A similar percentage of the phase 1 group and the phase 2 delayed group made the correct choice E.

A fairly large percentage of all the groups once again took the reactivity series to be some sort of a "rate series". Since this is already shown in previous questions to be a widely held misconception, it is not unexpected that this should happen. Hence the percentage choosing option D might well be higher if there were other, less popular distractors.

If one considers the intended outcome for this question to be a decrease in the number who believe there is only one reactivity series then the percentage choosing option D by both the phase 2 delayed and undelayed groups were significantly better that the phase 1 group. This implies an increased awareness that the reactivity of a substance depends on the co-reactant. Most of the increase has occurred for option B.

The pack, during the latter part of session 1 and during session 2, indicated that the order of the series is dependent on the criteria used to measure reactivity. The "pack" drawn attention during the pre-course discussion, in session 2 that magnesium reacts faster than calcium with oxygen but calcium reacts faster than magnesium with water.

There appears therefore to have been partial success for the course implied by these outcomes. It is interesting to note that, again the phase 2 undelayed group seem also to have moved away from choice D, but to a lesser extent.

Question 8

Objective: To determine whether students take the position of the elements in a reactivity series to be invariant.

Question 8

Which of the following statements about the metal reactivity series is true?

	Options	Phase 1	Phase 2/%option	
		% /option	Undelayed	Delayed
-	No response	-	0.7	1.1
A.	Elements high up in the series have a lot of energy.	10,0	27.5	14.3
B.	Metals higher up in the series will react *faster* with solutions of metal salts than metals lower down.	22,5	23.2	37.5
C.	Those metals immediately above hydrogen will react with dilute acids to produce hydrogen *faster* than a metal further up.	6,1	6.5	5.6
D.	The order of the reactivity series for the metals *never* changes irrespective of the substances they react with.	44,3	30.4	23.8
#E.	None of the above statements is correct.	17,1	11.6	17.6

of reactivity for the specific case of the pre-course work was discussed. Rate, cell voltage and energy measurements as possible criteria with which to compare reactivity was emphasized during the discussion of the pre-course work in session 2.

Approximately 18-20% of all the groups chose the correct option realising that the series was not a rate series. Hence the course seems to have had no influence in this regard.

In the course the possibility of different approaches to measuring reactivity was drawn to the teachers' attention. If this concept was taught to their students it would be understandable if their students were not sure that options C was correct.

Against this background a plausible correct response would be option E. Significantly more of the phase 2 delayed group chose this option than the phase 1 group and the phase 2 undelayed groups showed a similar tendency.

The total percentage choosing options C and E (40%) for this question is then comparable with the approximate percentage choosing option E (31%) for question 5.

B.	The reaction in test tube (1) will be *faster* than that in test tube (2), because bromine is more reactive than iodine.	45,3	34.8	31.9
#C.	The *speed* at which the reaction in the respective test tubes will take place cannot be predicted from the reactivity series.	20,6	18.8	19.3
D.	The reaction of chlorine with both solutions will not be spontaneous because *no heat* is supplied.	10,3	15.9	9.5
E	None of the above statements is correct.	9,3	15.2	21.6

Discussion.

18-20% of both the phase 2 groups correctly indicated that the rates of reaction could not be predicted.

10-13% fewer students of both phase 2 groups as compared to phase 1 hold the view that a reactivity series is a series that gives information about the speed with which the element will react. The sum of options A and B reflect the above assertion.

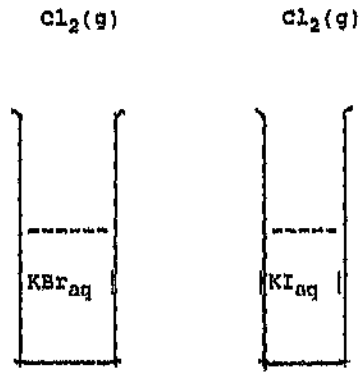
The reaction of halogens with the halides was given as pre-course work in the "pack". During session 2 the expert or scientific view

Question 7.

Objective: Interpretation of the halogen reactivity series.

Question 7

Chlorine is bubbled at the same rate through solutions of KI and KBr, in the respective test tubes (1) and (2). The solutions are of equal concentration and of equal volume. From the halogen reactivity series given below, the following can be concluded:



Halogen reactivity series

F_2

Cl_2

Br_2

I_2

	Options	Phase 1	Phase 2/%option	
		% /option	Undelayed	Delayed
-	No response	1,0	-	3.6
A.	The reaction in test tube (2) will be *faster* than that in test tube (1), because chlorine is *higher up* in the reactivity series from iodine than from bromine.	13,5	15.2	14.0

for correct option D (IV) was less for phase 2 students than phase 1, whilst both options B and E increased in popularity. It may be that teachers had explained that there is a variety of reactivity series and some are based on relative rates of reaction. Hence they would be correct in rejecting D. The given metal reactivity series (from textbook) is not defined; hence one cannot presume that they should know it is an electrochemical/equilibrium-based one. Furthermore the question may not have directed them forcibly enough to the given reactivity series.

The contrast with Q5 is remarkable. Maybe the specific case quoted in Q5 (or very similar case) was discussed in class and established as an equilibrium, not a rate comparison.

In retrospect it appears that the question is in fact unsatisfactory because it offers no option to students who understand that a reactivity series may be based on both rate and equilibrium aspects.

Question 6.

Objective: To ascertain students interpretation of a reactivity series.

Question 6

Consider the following statements about the metal reactivity series.

I. Compounds of metals at the top of the series decompose *more readily* than compounds of metals at the bottom.

II. A reactivity series is a series in which the metal reacting the *fastest* is placed at the top.

III. A reactivity series predicts the *relative speeds* of reaction of metals when reacting with any substance.

IV. A reactivity series gives *no information* as to *how fast* a reaction of a metal would occur.

Which of the above statements would you consider to be most appropriate?

	Options	Phase 1 %/ option	Phase 2/%option Undelayed	Delayed
-	No response	0,5	0.7	-
A.	I	7,6	8.0	6.4
B.	II	23,2	23.9	33.3
C.	I,II & III	34,9	39.1	33.6
#D.	IV	23,2	13.8	9.5
E.	III	10,7	14.5	17.4

Discussion.

This is a general question about a reactivity series. The percentage

However the phase 2 undelayed group also did significantly better.

There was no significant difference between the two, phase 2 groups. The "pack" emphasized in activity card 2, during session 2 that calorimetric measurements can be used to measure enthalpy values and hence draw up a reactivity series. Furthermore attention was drawn to the energy that can be given off in these displacement type of reactions and that the energy liberated can be used to rank the elements in a reactivity series. The better results of both the phase 2 groups may be ascribed to the influence of the contents in the pack on the teacher's understanding and/or teaching methods.

The fact that both phase 2 groups exhibited similar changes as compared with the phase 1 group suggests some transference of ideas may have been taking place whilst the course was still in progress. That is the teachers on the course who were not delaying their teaching, were correcting their own ideas and hence changing their teaching on a continuing basis.

B	Zinc will react *slower* than lead with the copper sulphate solution.	5,1	5.8	5.0
C	Both metals would react with the same speed.	17,1	5.1	1[illegible].6
D	Copper will be deposited *more rapidly* in beaker (1) than in beaker (2) because zinc displaces copper ions *faster* than lead does.	37,5	17.4	20.2
#E	None of the above statements is correct.	9,2	37.0	31.1

Discussion.

All the options, except the correct one E, invoked a connection between reactivity and relative rates of reaction.

63-68% of the phase 2 students linked their response only to rate, markedly better than the 91% of the phase 1 students.

Students choosing these options may in[illegible]flect the unclear manner in which some of the current stand[illegible] texts are written.

Approximately 22% more of the phase 2 students chose the correct option (E) as compared to phase 1.

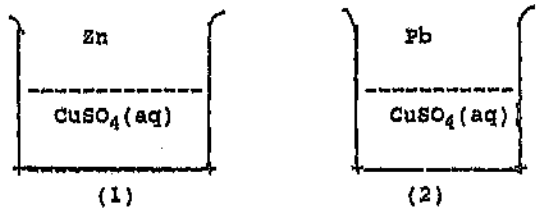
A Chi square test indicated that the 31% correct of the phase 2 delayed group is significantly better than the 9% of phase 1.

Question 5.

Objective: To ascertain students interpretation of a reactivity series.

Question 5

Equal numbers of moles of lead and zinc are placed in the same concentrations of copper sulphate solutions in respective beakers. (see diagram)



The reactions in the respective beakers are given below

1. $Zn(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$

2. $Pb(s) + CuSO_4(aq) \longrightarrow PbSO_4(aq) + Cu(s)$

Which of the following statements can be inferred from the accompanying metal reactivity series?

	Options	Phase 1 %/options	hase 2/%option Undelayed	Delayed
-	No response	0,5	0.7	3.4
A	Zinc will react *faster* than lead with the copper sulphate solution.	30,2	34.1	29.7

Table 1: Summary of original and alternative analysis of outcome on the reactivity questionnaire - phase 2 teaching delayed and phase 1.

Concept or Misconception	Q's & option	Original Outcome: Phase 2- Teaching delayed	Phase 2 %	Phase 1 %	Q's & option	Alternative Outcome: Phase 2- Teaching delayed	Phase 2 %	Phase 1 %
catalyst	1D	no change expected	8.4	7.5	1D	no change expected	8.4	7.5
reactivity series	2B	no change- no test of rate link expected	62.7	66	2B	no change- no test of rate link expected	62.7	66
spontaneous reaction	3E	improved	27.5	11	3E	improved	27.5	11
exo/endo	4A	improved	56.6	37	4A	improved	56.6	37
reactivity link to rate	5E	improved	31.1	9	5E	improved	31.1	9
	6D	negative outcome- faulty question	9.5	23	6D	negative outcome- faulty question	9.5	23
	7C	no improvement	19.3	19	7E*	improved	21.6	9
single reactivity series	8E	no change	17.6	17	8D*	improved	23.8	44

* indicates more appropriate option in the light of the conceptual change course offered.

CHAPTER 8: SUMMARY OF FINDINGS ABOUT THE INFLUENCE OF THE COURSE FOR TEACHERS ON THE LEARNING BY THEIR STUDENTS

This chapter briefly reviews the salient aspects of the study and illustrates some specific and general outcomes of phase 2.

The course developed for improving teacher understanding of chemical reactivity spanned over five months. During this period the contact time with the teachers was approximately 10 hours. An "Understanding Reactivity" pack designed according to constructivist guidelines was used to facilitate teacher understanding of reactivity.

Discussions with the teachers during the course indicated that the course was informative and sequenced meaningfully.
Verbal and written contributions made by the teachers during the course signaled that thoug' had been given to aspects that need to be considered when teaching the topic.

A summary of the original and alternative analysis of outcomes of responses to the reactivity questionnaire. (Tables 1 and 2)

An summary of the original and alternative analysis of outcomes of the reactivity questionnaire is contained in table 1 and 2. Table 1 illustrates a comparison between the phase 2 delayed groups and the phase 1 group.
Table 2 illustrates a comparison between the phase 2 undelayed group and the phase 1 group.
As previously explained in the alternative analysis the most appropriate option for question 7 was E and for question 6 was D, (see tables 1 and 2).

The 10 % scientifically correct responses by the phase 2 delayed group of standard 8 students can probably be ascribed to their teachers participation in the conceptual change course.

The course using the "Understanding Reactivity" pack drew attention to the scientific view about reactivity during sessions 1 and 2. Neither the concept reactivity nor the different approaches used to measure reactivity are explained in current school physical science textbooks. The claim that the conceptual change course may have been responsible, for moving teachers and consequently their students towards giving both kinetic and thermodynamic considerations to the concept of reactivity would therefore seem reasonable.

Comparison of various categories of students during phase 1 and 2

The responses by the standard 8 students in phase 1 and 2 and the standard 10 students in phase 1 on the concept reactivity are summarised in the table.

Phase - standard and questioning method	Scientifically correct explanation
Phase 1 - std. 8 Interview	None of the students responded correctly
Phase 1 - std. 10 Open ended question	0%
Phase 2 - std. 8 teaching delayed Open ended question	10%
Phase 2 - std. 8 teaching undelayed Open ended question	0%

The absence of a scientifically correct explanation of reactivity was evident amongst standard 8 students that were interviewed during phase 1. Furthermore, none of the standard 10 students in phase 1 gave a scientifically correct explanation of reactivity even though they had two additional years of formal teaching.

R: Reactivity is the power an element has to react with another. It indicates whether an element can react *fast* or *slow*.

R: When compounds and substances are placed in a series according to how they react. The *faster* they react they are placed at the top of a series and the *slower* at the bottom of the series.

R: A reactivity series is a series in which elements are placed according to their *speed* .

3. Energy explanations.

R: The element with the most energy is placed at the top and the one with the least energy is at the bottom.

R: The most energetic substance is followed by a less energetic substance.

The responses of 138 students whose teachers participated in the course but did not delay the teaching of reactivity have not been quoted. The percentage responses by these students for the categories mentioned below are approximately the same as those of the students taught by their teachers who delayed the teaching of reactivity. However no scientifically correct explanations were given by these students for reactivity and reactivity series. The decrease in the percentage of scientifically correct explanations for reactivity and reactivity series was reflected mainly by an increase in anthropomorphic explanations and explanations linked to energy and/or rate respectively.

Students responses to the concept of reactivity series.

1. *Scientifically correct.*

R: It is a series in which the elements are placed in an approximate order. The order may change depending on the substance the element reacts with.

R: It is a series in which the elements are placed in an approximate order.

2. *Circular explanations.*

R: The reactivity series is arranged so that the most reactive substance is at the top and the least reactive substance at the bottom.

R: Indicates which substances are *highly reactive* and which are not highly reactive.

R: It is the ordering of elements according to increasing or decreasing *reactivity.*

R: It is how the elements is listed in the periodic table. From top to bottom and left to right

R: It is a series , ordering elements according to increasing or decreasing *activity.*

R: The series obviously ranges from substances of *high reactivity* to that of low reactivity

3. *Rate explanations.*

R: The metal that reacts the fastest is on top and the metal that reacts the slowest is at the bottom of the series.

3. Rate viewpoint.

R: Reactivity determines *the length of time* which the reaction takes place.

R: The *rate* at which metals react. How *fast* or how slow they form products.

R: The *rate* at which a compound or an element would react. How fast or how slo this would be done. A catalyst would increase the reactivity.

R: It probably refers to the ability of chemicals to react *quickly or slowly.*

R: The *rate* at which substances react with each other, degree of spontaneity of reactions.

R: How fast a metal or chemical will react with another substance. The *rate* at which the substance will react or whether it is a spontaneous reaction or not.

R: This means how *rapidly* or vigorously a metal would react with another.

R: Each substance has a certain reactivity which means that some substances react *faster* or more effective than others.

4. Circular explanations

R: Reactivity of a substance depends on how reactive the substance is. Substances can react continuously with one another. Alkali metals are most reactive.

R: The term means how reactive a substance is. All elements in a reactivity series react differently.

Students responses to the concept of reactivity

1. *Scientifically correct.*

R: It is the ability of a substance to form a product in a chemical reaction.

R: The tendency of reactants to form products.

R: Substances may or may not have the tendency to form products in a chemical reaction.

R: It is the ability of one substance to react with another substance to form a product in a chemical reaction.

R: It is the tendency for reactants to form products. It can depend on speed or the energy change in a reaction.

R: The ability of an element to react. The reaction can be spontaneous or non spontaneous. Exothermic or endothermic. Fast or slow.

R: The capability of an element to react. The reaction can be spontaneous or non spontaneous.

2. *Anthropomorphic explanation.*

R: The reactivity of the reaction has to do with the *power* of the reaction.

R: The *vigour* with which chemicals combine gives the reactivity.

R: How *vigorously* a metal reacts.

R: Reactivity *refers* to how a metal can combine and how it reacts with other components. If bright sparks, loud explosions and a lot of *vigourous* things are happening the component is said to be very reactive.

Reactivity Series

1. *Scientifically correct explanation.* Approximately 10% of the students showed an understanding of a reactivity series similar to that held by the science education community. Approximately 5% of the 10% responses in this category are quoted below.

2. *Circular explanations.* Approximately 10% of the students gave a circular explanation of the concept of a reactivity series. The term reactivity was used to explain the concept reactivity series. Approximately 15% of the 10% responses in this category are quoted below.

3. *Rate explanation.* Approximately 40% of the students indicated that the elements are ordered in terms of the speed with which they react. Approximately 10% of the 40% responses in this category are quoted below.

4. *Energy explanations.* Approximately 10% of the students indicated that the elements are ordered in terms of the energy they have. The more energy they have the higher they are in the reactivity series. Approximately 10% of the 40% responses in this category are quoted below.

5. *No response.* Approximately 10% of the same students who did not respond to the previous question also did not respond to this question.

Student responses have been listed using the letter "R". The responses are reflected as they appear on the original questionnaire. Discussions of the responses will follow later.

The responses to the open ended questions, by the standard 8 students whose teachers delayed the teaching of reactivity until the completion of the course, will first be considered. The responses of the students can be respectively assigned to the distinct categories given below.

The responses of 357 standard 8 students to both these questions were analysed.

Reactivity

1. *Scientifically correct explanation.* About 10 % of students expressed reactivity in a scientifically correct way. Approximately 20% of the 10% responses in this category are quoted below.
2. *Anthropomorphic explanation.* About 5% of students expressed reactivity in an anthropomorphic way. Approximately 10% of the 5% responses in this category are quoted below.
3. *Rate explanation.* About 40% of the students linked their descriptions of reactivity to rate. Approximately 20% of the 40% responses in this category are quoted below.
4. *Intelligible but "circular" explanations.* Circular explanations of the concept of reactivity were given by approximately 10% of the students, indicating a lack of explanatory power. Approximately 5% of the 10% responses in this category are quoted below.
5. *Unintelligible explanations.* Approximately 30% of the responses were unintelligible. These have not been quoted.
6. *No responses.* Approximately 5% of the students, did not respond to this question.

In both cases the phase 2 undelayed group showed somewhat less improvement then the delayed group.

Summary of the overall results of the phase 1 group compared with the phase 2 teaching delayed and undelayed groups on the reactivity questionnaire, calculated in the original and alternative manner. (APPENDIX N2)

Two sets of percentages are given below. One for a total of 8 multiple-choice questions and the other for a total of 5 (excluding Q1, Q2 & Q6).

Basis of calculation	Phase 1 N=411	Phase 2 N=138 - undelayed	Phase 2 N=357 - delayed
Original(8Q)	24%	25%	29%
Alternative(5Q)	23%	32%	41%

7.3 Analysis of the open ended questions

Standard 8 students were also tested on their understanding of the terms reactivity and reactivity series by means of the following open-ended questions which were included in the reactivity questionnaire.

9. Explain in about five lines what you understand by the following term(s).

9.1 Reactivity

9.2 Reactivity series.

Alternative comparison of the phase 2 delayed and undelayed groups with the phase 1 group on the reactivity questionnaire.(Appendix M2)

A students t-test on the overall percentages obtained by the phase 2 delayed and undelayed groups and the phase 1 group showed that both phase 2 groups performed significantly better than the phase 1 group.

Phase 2 undelayed group - 32%

Phase 2 delayed group - 41%

Phase 1 group - 23%

As regards individual questions, a chi-square test indicates that for questions 7 and 8 both the phase 2 delayed and undelayed groups did significantly better than the phase 1 group. There is a significant difference between the phase 2 groups.

Question and option	Phase 1 / %	Phase 2 / %	
		undelayed	delayed
7E	9.3	15.2	21.6
8D	44.3	30.4	23.8

Both the groups of phase 2 students appear to show benefit from the course for their teachers. Teachers who did not delay the teaching of reactivity appeared to transmit what they were learning during the course to their students since in some cases their teaching was running parallel or slightly ahead of the course that was presented.

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- conceptual change courses that model the strategies and ideas being advanced, for student teachers, on the same or other topics, can be integrated into the teacher training curriculum.

- follow into the classroom and test the standard 8 students, exposed to the teachers who have gone through the conceptual change course, on the rate and equilibrium questionnaire.

- Interview teachers exposed to the conceptual change course, to identify their level and scope of understanding, on reactivity related aspects, tested in the rate and equilibrium questionnaire.

in-service work in teacher training; (ii) for school based INSET in one school (iii) by a cluster of schools or interested individuals teachers from a number of schools.

Schuell[69] has pointed out that an adequate understanding of science education must consider the prior and potential understanding of both the learner and the educator since the educator has beliefs that influence his teaching.

The approach adopted in this study accords with the ideas of Schuell and may be a model for fundamental improvement in science teaching. The approach involves finding out teacher's views about a particular topic and then designing and implementing a conceptual change course of in-service education on this topic. Systematic application of this approach across a range of core topics at different levels could result in a permanent and fundamental improvement in science teaching.

Strengthening of teacher competence and confidence would also result in improved motivation with self-evident consequences for the learners in their classrooms.

Implications for future research

Further research closely related to this study (and perhaps emanating from this study) that might be conducted in the future are suggested:

- in-service courses that model the strategies and ideas being advanced, on the same or other topics, can be conducted to see if similar findings are generalisable.

" In spite of the evidence from this study that primary teachers can acquire a better understanding of aspects of force and energy, the question remains of whether this means they are able to teach these scientific concepts more effectively to children".

This study does however provide evidence of a statistical nature, showing that the teachers were more effective and that their students benefited.

A course designed in a holistic manner attempting the conceptual change of student teachers can be beneficial if it is structured so that during their training:

- attention is drawn to the relevant aspects of the syllabus;
- related concepts in the syllabus are linked;
- pedagogical skills to impart the newly acquired information complement the course.

Because teachers need both conceptual and pedagogical knowledge and skills it is important that both are considered when planning in-service or pre-service education course.

Teachers were not followed into the classroom and whilst according to Millar[68] the constructivist model of learning does not imply a specific model of instruction, the outcomes do suggest that learners' in the classroom were actively engaged by their teachers who acquired pedagogical knowledge and skills during the conceptual change course.

The "Understanding Reactivity" pack is flexible and in the hands of a competent facilitator or course leader can be used for (i) initial

CHAPTER 9: CONCLUSIONS

The first phase of the research made an intensive study of the conceptions of students by using interviews and questionnaires on aspects of rate of reaction, chemical equilibrium and reactivity. Sources of misconceptions were identified and a natural consequence was an attempt to remedy the problems.
This phase investigated student understandings of reactivity an area which is notorious for its complexity and subtlety. Unlike most other studies of this sort, however by comparison of the views of standard 8 students with those of standard 10 students (as well with the understanding of teachers), insights have been obtained into the origins of student conceptions. The correspondence between the standard 8 and standard 10 levels of understanding is surprising, if not amazing, and implies a very significant message to science educators.

The second phase of the study attempted to improve teacher understanding of reactivity related concepts by means of a conceptual change course and also to ascertain if the students they taught ultimately benefited. In fact the students of teachers who delayed the teaching of reactivity until they had completed the conceptual change course did significantly better than those students whose teaching was not delayed.

Summers and Kruger's[51] concluding remarks about their conceptual change courses for primary teachers may be quoted:

3. Students also again offered circular explanations i.e the word reactive was used to explain the term reactivity.

4. A large percentage of students gave unintelligible responses. One wonders if it is a cognition problem or a language problem or both that gave rise to the unintelligible responses.

It must be acknowledged that there are weaknesses in this study in that:

-pre and post testing was absent and;

-the teachers were not followed into the classroom.

Nevertheless the positive influence of the conceptual change course complemented by the "Understanding Reactivity" pack seems clearly evident from the many facets of observation and analysis reported here.

The standard 8 students in phase 2 taught by teachers who did not delay their teaching appeared to also have benefited from the course. However the improvement was to a lesser extent than the group that received delayed teaching.

It seems reasonable to ascribe the improvement to more effective teaching after teachers had participated in the course and used the "pack".

2.2 During phase 1 when responses about reactivity were elicited from the interviews, none of the standard 8 students had a scientifically correct view of reactivity.

2.3 None of the standard 10 students during phase 1 showed a scientifically correct view of reactivity when responding to the same question on reactivity in the rate and equilibrium questionnaire.

General observations

1. Many standard 8 students taught by teachers who had completed the course still seemed to be looking at the term reactivity only from a kinetic viewpoint.
   However a significantly smaller percentage of students held this belief than was observed during phase 1.

2. A small but significant percentage of the standard 8 students did not link the concept of reactivity to *rate* only.
   This presumably reflects a better understanding of the concept reactivity, by the students who received teaching from the teachers who had completed the course.

   During phase 1 of the investigation the responses of standard 10 students to the same open-ended question did not give any consideration to the thermodynamic and equilibrium aspect of reactivity even though they had two additional years of formal teaching.

1.2 Table 2 shows responses for questions 5,7 and 8. These questions were based on the reactivity series and each had more than one distractor related to *rate*. The percentages indicate the percentage of students who chose responses invoking a connection of reactivity with relative rates of reaction.

Table 2

Question	Phase 1	Phase 2	
		Undelayed	Delayed
5(A+B+C+D)	90%	62%	68%
7(A+B)	59%	50%	47%
8(B+C)	28%	30%	41%

As much as 62-68% may believe in this link as compared to 90% in phase 1. Where other options are particularly attractive, the percentages of students choosing this link is reduced.
The data in the table 2 indicates mixed success in teaching the idea that reactivity may be judged in terms of criteria other than rate.

2. Comparison of responses with the open ended question on reactivity during phase 2.

2.1 A small but significant percentage (10%), of phase 2 students whose teaching was delayed by their teachers until the completion of the course, explained reactivity in a scientifically correct manner.

2. The overall percentage achieved by the phase 2 undelayed group (32%) was also improved but to a lesser extent when compared to the overall percentage achieved by the phase 1 schools (23%).

Summary of concepts tested, indicating improved teaching of scientific view.

To summarise the outcomes of the alternative analysis the following tables and open ended questions provide:

1. Comparison of the extent to which the scientific view was expressed by the phase 2 undelayed and delayed groups of students with the phase 1 group of students. (Tables 1 and 2)

   1.1 In highlighting the comparisons questions 1, 2 and 6 have been excluded for reasons given earlier. Table 1 shows this comparison in respect of the concepts spontaneous reaction, endothermic/exothermic reactions and reactivity series.

Responses are drawn from questions 3,4, 5, 7 and 8.

Table 1

Question option	Std. 8 Phase 1 %	Phase 2 Undelayed %	Phase 2 Delayed %	Concept tested
3E	10	7.2	27.5	Spontaneity
4A	37	39	57	Exothermic / endothermic
5E	9	37	31	Reactivity series based on different approaches
7E	9	15	22	Reactivity series based on different approaches
8D	44	30	23	Single reactivity series

On a question by question basis excluding questions 1,2 and 6 the original analysis shows the phase 2 delayed group did better than the phase 1 group. The alternative analysis however indicates a much greater benefit from the course.

The original and alternative analysis of outcomes where teaching was not delayed show mixed results. These teachers did not delay the teaching of reactivity and, as the course progressed seem to have changed partially the basis of their teaching. Some topic questions suggest a positive intervention by the teacher, others do not.

A summary of the overall results according to the original and alternative analysis of outcomes.

The original analysis of the overall results indicates:

1. The overall result of the phase 2 schools, with delayed teaching (29%) is significantly better than that of phase 1 schools (24%).

2. The overall result of the phase 2 schools, with undelayed teaching (25%) is not significantly different from that of phase 1 schools (24%).

3. The overall result of the phase 2 schools, with delayed teaching (29%) is significantly better than that of the phase 2 schools with undelayed teaching (25%).

An alternative analysis of the outcomes indicates:

1. The overall percentage achieved by the phase 2 delayed group (41%) nearly doubled when compared to the overall percentage achieved by phase 1 schools (23%).

Table 1: Summary of original and alternative analysis of outcome on the reactivity questionnaire - phase 2 teaching undelayed and phase 1

Concept or Misconception	Q's & option	Original Outcome: Phase 2- Teaching undelayed	Phase 2 %	Phase 1 %	Q's & option	Alternative Outcome: Phase 2- Teaching undelayed	Phase 2 %	Phase 1 %
catalyst	1D	no change expected	7.2	7.5	1D	no change expected	7.2	7.5
reactivity series	2B	no change- no test of rate link expected	66	66	2B	no change- no test of rate link expected	66	66
spontaneous reaction	3E	outcome negative	7.2	11	3E	outcome negative	7.2	11
exo/endo	4A	no change	39	37	4A	improved	39	37
reactivity link to rate	5E	improved	37	9	5E	improved	37	9
	6D	negative outcome- faulty question	14	23	6D	negative outcome- faulty question	14	23
	7C	no change	19	19	7E*	some improvement	15	9
single reactivity series	8E	negative outcome	12	17	8D*	improved	30	44

* indicates more appropriate option in the light of the conceptual change course offered.

Appendix A1

STD

GRADE

CHEMICAL EDUCATION PROJECT

QUESTIONNAIRE ON CERTAIN ASPECTS OF CHEMISTRY

MULTIPLE -CHOICE QUESTIONS

ANSWER SHEET

Study each question and its suggested answers indicated with the letters A, B, C, D, and E. When you have decided on the most appropriate answer, draw a cross over the corresponding letter on the answer sheet .

You may make use of the accompanying reactivity series for the metals, to answer some of the questions.

PLEASE HAND IN THE ANSWER SHEET AS WELL AS THE QUESTIONNAIRE

ANSWERS

	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7					
8					

APPENDIX A1

PHASE 1

APPENDICES

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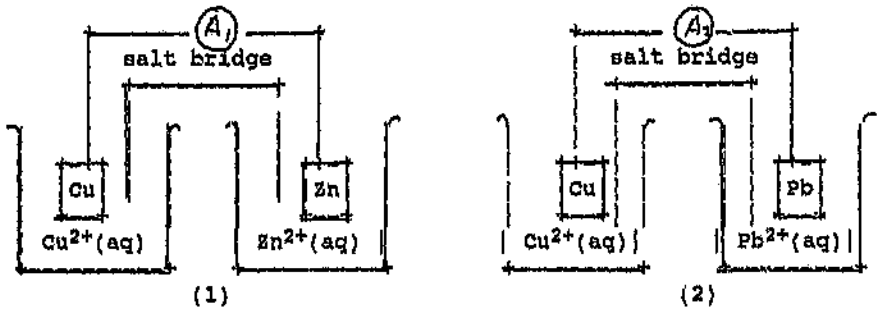
QUESTION 5

In the following electrochemical cell representations ammeters A_1 and A_2 are connected with identical copper wires to the respective cells.

The respective *standard cell potentials* are given below.



(1) Cu^{2+} + Zn(s) --------> Zn^{2+} + Cu(s) $E^{\circ} = 1.1$ V
(2) Cu^{2+} + Pb(s) --------> Pb^{2+} + Cu(s) $E^{\circ} = 0.47$ V

From these data it can be concluded that:

A. Zn will go *faster* into solution than Pb.
B. Pb will go *faster* into solution than Zn.
C. The ammeter indicating the larger current cannot be predicted.
D. Higher cell voltage implies higher cell current.
E. None of the above statements is correct.

QUESTION 6

The *standard* reduction potentials for the following half reactions are given below.

$F_2(g)$ + 2e --------> $2F^-(aq)$ $E^{\circ} = +2.87$ V
$Cl_2(g)$ + 2e --------> $2Cl^-(aq)$ $E^{\circ} = +1.36$ V
$Br_2(g)$ + 2e --------> $2Br^-(aq)$ $E^{\circ} = +1.06$ V
$I_2(g)$ + 2e --------> $2I^-(aq)$ $E^{\circ} = +0.54$ V

The following information can be inferred from the data given.

A. Fluorine is the strongest reducing agent.
B. Fluorine will react *faster* than iodine when reacting with sodium.
C. Iodine is the strongest oxidizing agent.
D. Fluorine accepts electrons *faster* than iodine as is indicated by fluorine having a larger E° value.
E. None of the above statements is correct.

QUESTION 3

The *standard cell* potentials for the following hypothetical reactions are given below:

(1) A + B --------> C + D E° = +1.1 V
(2) E + F --------> G + H E° = -0.5 V

From these data the following can be concluded

I. Reaction 1 is a spontaneous reaction and therefore a faster reaction
II. Reaction 2 is exothermic.
III. Reaction 1 is slower than reaction 2
IV. Adding a catalyst can speed up the reaction and thus change the E° value of the respective reactions.
V. None of the above statements is true.

Choose the correct statement(s)

A. III
B. I & II
C. IV
D. V
E. I

QUESTION 4

Standard cell potentials for the following reactions are given below.

(i) $Cl_2 + Ni(s) = Ni^{2+} + 2Cl^{-}$ E° = +1.60 V

(ii) $Br_2 + 2Fe^{2+} = 2Br^{-} + 2Fe^{3+}$ E° = +0.29 V

From these data it can be concluded that:

A. Reaction (i) is faster than reaction (ii) because the E° value is larger.
B. Reaction (ii) is faster than reaction (i) because the E° value is smaller.
C. Reaction (i) is faster because chlorine is a stronger oxidant than bromine.
D. Reaction (ii) is faster because the concentration of Fe^{2+} is twice the concentration of Ni.
E. The faster of the two reactions cannot be predicted.

MULTIPLE-CHOICE QUESTIONS

QUESTIONS

QUESTION 1

The balanced chemical equation for the reaction between hydrogen and nitric oxide is

$$2H_2 + 2NO \longrightarrow 2H_2O + N_2$$

Given this equation decide how the rate of the reaction is influenced by doubling the concentration of NO:

A. the rate of the reaction would be doubled.
B. the rate of the reaction would be four times greater.
C. the rate of the reaction would be halved.
D. there would be no effect on the rate of reaction.
E. the influence on the *rate* cannot be predicted from the balanced chemical equation alone.

QUESTION 2

The chemical equations given below represent two hypothetical reactions.

$$A + B \longrightarrow C + D \qquad \Delta H = -x \text{ kJ} \quad (1)$$

$$D + E \longrightarrow F + G \qquad \Delta H = +y \text{ kJ} \quad (2)$$

If the two reactions occur at the same temperature which one of the following statements is correct?

I. Reaction 1 occurs *rapidly*.
II. Reaction 2 occurs *slowly*.
III. Reaction 1 is *always* faster than reaction 2.
IV. Reaction 2 *may* be faster than reaction 1.
V. Reaction (1) is spontaneous and reaction (2) is non spontaneous.

Choose the correct statement(s)

A. III
B. I,II, V
C. IV
D. V
E. I

CHEMICAL EDUCATION PROJECT

QUESTIONNAIRE

PRELIMINARY REMARKS

The purpose of this questionnaire is to determine the views of pupils pertaining to certain fundamental concepts related to understanding of certain aspects of chemistry.

This questionnaire should take approximately 30 minutes to complete. Consider the options carefully and take note of the words printed in *italics*.

Thank you for your co-operation. I will provide solutions to the questionnaire. I trust that your participation will clarify any alternative concepts that you may have and consequently make your learning process more meaningful.

Appendix B1

STD	GRADE

CHEMICAL EDUCATION PROJECT

ASPECTS OF RATES OF REACTION AND CHEMICAL EQUILIBRIUM

QUESTIONNAIRE

MULTIPLE -CHOICE QUESTIONS

ANSWER SHEET

Study each question and its suggested answers indicated with the letters A, B, C, D, and E. When you have decided on the most appropriate answer, draw a cross over the corresponding letter on the answer sheet

Questions 1- 7 are multiple choice questions
Questions 8 is an open ended question. (Space has been provided to answer this question).

PLEASE HAND IN THE ANSWER SHEET AS WELL AS THE QUESTIONNAIRE

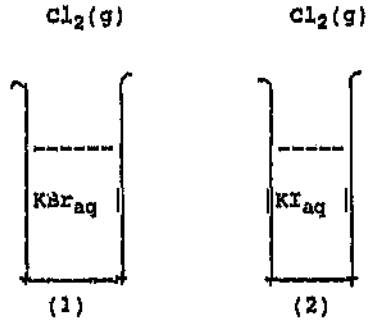
ANSWERS

	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7					

APPENDIX B1

QUESTION 7.

Chlorine is bubbled at the same rate through solutions of KI and KBr, in the respective test tubes (1) and (2). The solutions are of equal concentrations and of equal volume. From the halogen reactivity series given below, the following can be concluded:



Halogen reactivity series

F_2
Cl_2
Br_2
I_2

A. The reaction in test tube (2) will be *faster* than that in test tube (1), because chlorine is *higher up* in the reactivity series from iodine than from bromine.
B. The reaction in test tube (1) will be *faster* than that in test tube (2), because bromine is more reactive than iodine.
C. The *speed* at which the reaction in the respective test tubes will take place cannot be predicted from the reactivity series
D. The reaction of chlorine with both solutions will not be spontaneous because *no heat* is supplied.
E. None of the above statements is correct.

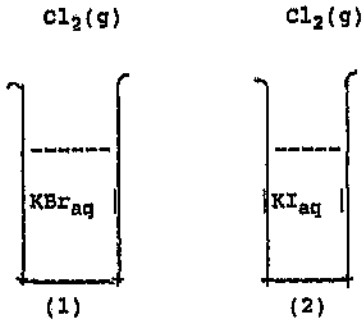
QUESTION 8

Which of the following statements about the metal reactivity series is true.

A. Elements high up in the series have a lot of energy.
B. Metals higher up in the series will react *faster* with solutions of metal salts than metals lower down.
C. Those metals immediately above hydrogen will react with dilute acids to produce hydrogen *faster* than a metal further up.
D. The order of the reactivity series for the metals *never* changes irrespective of the substances they react with.
E. None of the above statements is correct.

QUESTION 7.

Chlorine is bubbled at the same rate through solutions of KI and KBr, in the respective test tubes (1) and (2). The solutions are of equal concentrations and of equal volume. From the halogen reactivity series given below, the following can be concluded:



Halogen reactivity series

F_2
Cl_2
Br_2
I_2

A. The reaction in test tube (2) will be *faster* than that in test tube (1), because chlorine is *higher up* in the reactivity series from iodine than from bromine.
B. The reaction in test tube (1) will be *faster* than that in test tube (2), because bromine is more reactive than iodine.
C. The *speed* at which the reaction in the respective test tubes will take place cannot be predicted from the reactivity series
D. The reaction of chlorine with both solutions will not be spontaneous because *no heat* is supplied.
E. None of the above statements is correct.

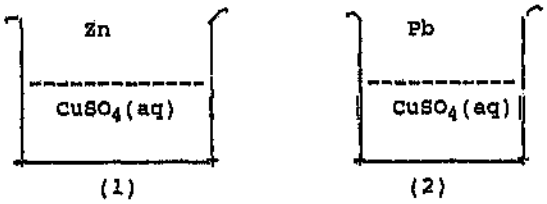
QUESTION 8

Which of the following statements about the metal reactivity series is true.

A. Elements high up in the series have a lot of energy.
B. Metals higher up in the series will react *faster* with solutions of metal salts than metals lower down.
C. Those metals immediately above hydrogen will react with dilute acids to produce hydrogen *faster* than a metal further up.
D. The order of the reactivity series for the metals *never* changes irrespective of the substances they react with.
E. None of the above statements is correct.

QUESTION 5.

Equal number of moles of lead and zinc are placed in the *same* concentrations of copper sulphate solutions in respective beakers. (see diagram)



The reactions in the respective beakers are given below

1. $Zn(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$

2. $Pb(s) + CuSO_4(aq) \longrightarrow PbSO_4(aq) + Cu(s)$

Which of the following statements can be inferred from the accompanying metal reactivity series:

A. Zinc will react *faster* than lead with the copper sulphate solution.
B. Zinc will react *slower* than lead with the copper sulphate solution.
C. Both metals would react with the same speed.
D. Copper will be deposited *more rapidly* in beaker (1) than in beaker (2) because zinc displaces copper ions *faster* than lead does..
E. None of the above statements is correct.

QUESTION 6.

Consider the following statements about the metal reactivity series.

I. Compounds of metals at the top of the series decompose *more readily* than compounds of metals at the bottom.
II. A reactivity series is a series in which the metal reacting the *fastest* is placed at the top.
III. A reactivity series predicts the *relative speeds* of reaction of metals when reacting with any substance.
IV. A reactivity series gives *no information* as to *how fast* a reaction of a metal would occur.

Which of the following statement would you consider to be most appropriate

A. I
B. II
C. I,II & III
D. IV
E. III

MULTIPLE-CHOICE QUESTIONS

QUESTION 1

The following statements are given below:

I. A catalyst speeds up the *rate* of the reaction without taking part in the reaction.
II. A catalyst increases the *yield* of the products in a reaction.
III. A catalyst *initiates* a reaction.
IV. A catalyst increases the rate of the reaction.

Which of the following statements do you consider to be definitely appropriate.

A. I
B. II
C. III
D IV
E III & IV

QUESTION 2.

Use the accompanying reactivity series for metals and hence choose the *most* appropriate response:

A. K reacts *faster* with oxygen than Na does.
B. The least reactive metal is Au.
C. K will react with *more* oxygen than Na.
D. the reactivity series can be used to predict which metal would react the fastest with sulphur.
E. None of the above statements is correct.

QUESTION 3.

A spontaneous reaction is a reaction that

A. always gives off energy.
B. always absorbs energy.
C. takes place without any delay.
D. occurs without heating it.
E. can occur, however it could be fast or slow.

QUESTION 4.

When Na is heated in a deflagrating spoon and then inserted in a gas jar of oxygen there is a vigorous reaction with oxygen accompanied by the emission of light. The reaction of Na with *oxygen* can be considered to be

A. exothermic because energy is *liberated* in the form of light.
B. endothermic because Na was *heated before* the reaction could take place.
C. spontaneous because the reaction was *rapid*.
D. non spontaneous because Na had to be heated.
E. catalysed because the *heat supplied* was a catalyst for the reaction.

CHEMICAL EDUCATION PROJECT

Questionnaire

PRELIMINARY REMARKS

The purpose of this questionnaire is to determine the views of pupils pertaining to certain fundamental concepts related to understanding of certain aspects of chemistry.

This questionnaire should take approximately 30 minutes to complete. Consider the options carefully and take note of the words printed in *italics*.

Thank you for your co-operation. I will provide solutions to the questionnaire. I trust that your participation will clarify any alternative concepts that you may have and consequently make your learning process more meaningful.

REACTIVITY SERIES FOR METALS

K

Ba

Ca

Na

Mg

Al

Zn

Fe

Pb

(H)

Cu

Hg

Ag

Au

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq87

Std	Mcq87		
Frequency Percent Row Pct Col Pct	0	1	Total
8	327 50.62 79.56 62.88	84 13.00 20.44 66.67	411 63.62
10	193 29.88 82.13 37.12	42 6.50 17.87 33.33	235 36.38
Total	520 80.50	126 19.50	646 100.00

Statistics for table of Std by Mcq87

Statistic	DF	Value	Prob
Chi-Square	1	0.627	0.429
Likelihood Ratio Chi-Square	1	0.633	0.426
Continuity Adj. Chi-Square	1	0.474	0.491
Mantel-Haenszel Chi-Square	1	0.626	0.429
Fisher's Exact Test (Left)			0.247
(Right)			0.814
(2-Tail)			0.471
Phi Coefficient		-0.031	
Contingency Coefficient		0.031	
Cramer's V		-0.031	

Sample Size = 646

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq86

Std Mcq86

Frequency / Percent / Row Pct / Col Pct	0	1	Total
8	316	95	411
	48.92	14.71	63.62
	76.89	23.11	
	62.08	69.34	
10	193	42	235
	29.88	6.50	36.38
	82.13	17.87	
	37.92	30.66	
Total	509	137	646
	78.79	21.21	100.00

Statistics for table of Std by Mcq86

Statistic	DF	Value	Prob
Chi-Square	1	2.459	0.117
Likelihood Ratio Chi-Square	1	2.506	0.113
Continuity Adj. Chi-Square	1	2.155	0.142
Mantel-Haenszel Chi-Square	1	2.455	0.117
Fisher's Exact Test (Left)			0.070
(Right)			0.953
(2-Tail)			0.133
Phi Coefficient		-0.062	
Contingency Coefficient		0.062	
Cramer's V		-0.062	

Sample Size = 646

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq85

Std Mcq85

Frequency / Percent / Row Pct / Col Pct	0	1	Total
8	373	38	411
	57.74	5.88	63.62
	90.75	9.25	
	64.53	55.88	
10	205	30	235
	31.73	4.64	36.38
	87.23	12.77	
	35.47	44.12	
Total	578	68	646
	89.47	10.53	100.00

Statistics for table of Std by Mcq85

Statistic	DF	Value	Prob
Chi-Square	1	1.967	0.161
Likelihood Ratio Chi-Square	1	1.924	0.165
Continuity Adj. Chi-Square	1	1.611	0.204
Mantel-Haenszel Chi-Square	1	1.964	0.161
Fisher's Exact Test (Left)			0.936
(Right)			0.103
(2-Tail)			0.183
Phi Coefficient		0.055	
Contingency Coefficient		0.055	
Cramer's V		0.055	

Sample Size = 646

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq84

Std	Mcq84		
Frequency Percent Row Pct Col Pct	0	1	Total
8	258 39.94 62.77 64.66	153 23.68 37.23 61.94	411 63.62
10	141 21.83 60.00 35.34	94 14.55 40.00 38.06	235 36.38
Total	399 61.76	247 38.24	646 100.00

Statistics for table of Std by Mcq84

Statistic	DF	Value	Prob
Chi-Square	1	0.487	0.485
Likelihood Ratio Chi-Square	1	0.486	0.486
Continuity Adj. Chi-Square	1	0.377	0.539
Mantel-Haenszel Chi-Square	1	0.486	0.486
Fisher's Exact Test (Left)			0.783
(Right)			0.269
(2-Tail)			0.502
Phi Coefficient		0.027	
Contingency Coefficient		0.027	
Cramer's V		0.027	

Sample Size = 646

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq83

Std Mcq83

Frequency / Percent / Row Pct / Col Pct	0	1	Total
8	366	45	411
	56.66	6.97	63.62
	89.05	10.95	
	62.35	76.27	
10	221	14	235
	34.21	2.17	36.38
	94.04	5.96	
	37.65	23.73	
Total	587	59	646
	90.87	9.13	100.00

Statistics for table of Std by Mcq83

Statistic	DF	Value	Prob
Chi-Square	1	4.489	0.034
Likelihood Ratio Chi-Square	1	4.774	0.029
Continuity Adj. Chi-Square	1	3.907	0.048
Mantel-Haenszel Chi-Square	1	4.482	0.034
Fisher's Exact Test (Left)			0.022
(Right)			0.990
(2-Tail)			0.034
Phi Coefficient		-0.083	
Contingency Coefficient		0.083	
Cramer's V		-0.083	

Sample Size = 646

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq82

Std Mcq82

Frequency / Percent / Row Pct / Col Pct	0	1	Total
8	141	270	411
	21.83	41.80	63.62
	34.31	65.69	
	58.51	66.67	
10	100	135	235
	15.48	20.90	36.38
	42.55	57.45	
	41.49	33.33	
Total	241	405	646
	37.31	62.69	100.00

Statistics for table of Std by Mcq82

Statistic	DF	Value	Prob
Chi-Square	1	4.347	0.037
Likelihood Ratio Chi-Square	1	4.320	0.038
Continuity Adj. Chi-Square	1	4.002	0.045
Mantel-Haenszel Chi-Square	1	4.341	0.037
Fisher's Exact Test (Left)			0.023
(Right)			0.985
(2-Tail)			0.042
Phi Coefficient		-0.082	
Contingency Coefficient		0.082	
Cramer's V		-0.082	

Sample Size = 646

APPENDIX D1

COMPARISON OF THE STANDARD 8 AND 10 RESULTS ON THE STANDARD 8 REACTIVITY QUESTIONNAIRE

Chi-squared test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq81

Std	Mcq81		
Frequency Percent Row Pct Col Pct	0	1	Total
8	380 58.82 92.46 63.44	31 4.80 7.54 65.96	411 63.62
10	219 33.90 93.19 36.56	16 2.48 6.81 34.04	235 36.38
Total	599 92.72	47 7.28	646 100.00

Statistics for table of Std by MCQ81

Statistic	DF	Value	Prob
Chi-Square	1	0.119	0.730
Likelihood Ratio Chi-Square	1	0.120	0.729
Continuity Adj. Chi-Square	1	0.035	0.851
Mantel-Haenszel Chi-Square	1	0.119	0.730
Fisher's Exact Test (Left)			0.430
(Right)			0.689
(2-Tail)			0.875
Phi Coefficient		-0.014	
Contingency Coefficient		0.014	
Cramer's V		-0.014	

Sample Size = 646

APPENDIX D1

2.5.2.2 Halogens.
The reaction of iodine with sodium and/or aluminium and with zinc (demonstrations).
Reactions of the halide ions (except F^-) with halogens except(F_2). The relative reactivity of the halogens . The colours of solutions of the halogens (except F_2) in chloroform, CS_2, xylene etc.

Minimum Practical Work : Physical Science Higher Grade

T implies to be done by the teacher.
P implies to be done by the pupil.

Standard 8

Aim of Experiment	Type
25.Investigate the burning of lithium, sodium, potassium calcium, magnesium ,iron and copper in oxygen and the properties of the products.	T
26.Investigate the thermal decomposition of copper(II) oxide, magnesium(II) oxide, lead(IV) oxide and mercury(II) oxide.	T
27.Investigate the reaction of sodium, potassium, calcium and magnesium and copper with water.	T
28.Investigate the reaction if any, of each of the metals: iron, zinc, magnesium and copper with solutions of salts of each of these metals had hence arrange them in an *activity series*.	T
29.Investigate the burning of carbon, phosphorus and sulphur in oxygen and the properties of their products.	T
30.Investigate the reactions of iodine with sodium, aluminium and zinc.	T
31.Investigate the reactions of:	
31.1 solutions of sodium bromide and sodium iodide with chlorine water.	P/T
31.2 solutions of sodium iodide with bromine water and hence arrange these halogens in order of *reactivity*	

Appendix C1

Syllabus standard 8.

2.5 Chemical Reactions Of certain metals.
Balanced equations must be written for all chemical equations which are studied. Balancing is done by counting atoms on both sides of the arrow.
Attention should be drawn to the fact that some reactions take place spontaneously and others do not.

Where necessary when sections 2.5.1 and 2.5.2 (chemical reactions) are dealt with, a brief reference can be made to the periodic table without going into too much theory (example electron structure)

2.5.1 Reaction of metals

2.5.1.1 Reactions with oxygen
Burning of lithium, sodium, potassium, calcium, magnesium, iron and copper in oxygen
The influence of solutions of metal oxide on an indicator (example litmus or bromothymol blue)
Heating of copper(II) oxide, magnesium oxide, lead(IV) oxide, mercury(II) oxide (the latter by demonstration only using a fume cupboard)
Observation of those giving off oxygen and how readily it is released

2.5.1.2 Reactions with water
Reactions of, sodium, potassium, calcium, magnesium, iron, copper with water, noting the rate at which these elements release hydrogen.
Arrangement of the metals in a rough activity series from the evidence collected. Attention should be drawn to the similarities of properties of group I metals (alkali metals)

2.5.1.3 Reactions with solutions of metal salts.
The addition of each of the metals iron, zinc, magnesium and copper to solutions of salts of each of these metals and arrangement in an activity series.
In some cases an increase in temperature is detectable.This indicates a release of energy.

2.5.2 Reaction of non metals

2.5.2.1 Carbon,phosphorus and sulphur
The reaction of each with oxygen only.The acidity of aqueous solutions of the oxides is noted.using an indicator.(e.g. bromothymol blue)
Carbonic acid and sulphurous acids as solutions of CO_2 and SO_2 respectively.

APPENDIX C1

QUESTION 7

In the equilibrium reaction represented by the following equation

$$3H_2 + N_2 \rightleftharpoons 2NH_3 \qquad \Delta H = -92kJ$$

increasing the temperature of the system:

A. Increases the rate of the forward reaction only.
B. Increases the rate of the reverse reaction only.
C. Increases the rate of both the forward and reverse reactions.
D. Decreases the rate of the reverse reaction since the reverse reaction is endothermic.
E. Has no effect on the rates of either the forward or the reverse reaction.

8. Explain in about five lines what you understand by the following term(s).

8.1 Reactivity

8.2 Reactivity series

All Schools: Std 8

Question 6

Answer	Frequency	Percent
	1	.
A	31	7.6
B	95	23.2
C	143	34.3
*D	95	23.2
E	44	10.4
X	2	0.5

Question 7

Answer	Frequency	Percent
	3	.
A	55	13.5
B	185	45.3
*C	84	20.6
D	42	10.3
E	38	9.3
X	4	1.0

Question 8

Answer	Frequency	Percent
	2	.
A	41	10.0
B	92	22.5
C	25	6.1
D	181	44.3
*E	70	17.1

Std. 8 questionnaire

Std 8's responses per school.

School: School no.1, Std 8

Question 1

Answer	Frequency	Percent
A	106	83.5
C	3	2.4
*D	9	7.1
E	9	7.1

Std. 8 questionnaire

Std 8's responses all schools.

Question 1

Answer	Frequency	Percent
A	324	78.8
B	6	1.5
C	11	2.7
*D	31	7.5
E	39	9.5

Question 2

Answer	Frequency	Percent
	1	.
A	65	15.9
*B	270	65.9
C	15	3.7
D	30	7.3
E	27	6.6
X	3	0.7

Question 3

Answer	Frequency	Percent
A	32	7.8
B	10	2.4
C	240	58.4
D	84	20.4
*E	45	10.9

Question 4

Answer	Frequency	Percent
	2	
*A	153	37.4
B	95	23.2
C	55	13.4
D	45	11.0
E	58	14.2
X	3	0.7

Question 5

Answer	Frequency	Percent
A	124	30.2
B	21	5.1
C	72	17.6
D	154	37.5
*E	38	9.2
X	2	0.5

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 REACTIVITY QUESTIONNAIRE- STD 8 AND STD 10 STUDENTS

General Linear Models Procedure

T tests (LSD) for variab : Toteight

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 Confidence= 0.95 df= 640 MSE= 1.391754
Critical Value of T= 1.96268

Comparisons significant at the 0.05 level are indicated by '***'.

School Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
School no.5 - School no.2	0.2210	0.4996	0.7782	***
School no.5 - School no.1	0.3059	0.5848	0.8638	***
School no.5 - School no.6	0.2357	0.6636	1.0915	***
School no.5 - School no.4	0.4064	0.7296	1.0528	***
School no.5 - School no.3	0.6750	1.0329	1.3907	***
School no.2 - School no.5	-0.7782	-0.4996	-0.2210	***
School no.2 - School no.1	-0.1687	0.0852	0.3391	
School no.2 - School no.6	-0.2480	0.1640	0.5760	
School no.2 - School no.4	-0.0719	0.2299	0.5318	
School no.2 - School no.3	0.1945	0.5332	0.8719	***
School no.1 - School no.5	-0.8638	-0.5848	-0.3059	***
School no.1 - School no.2	-0.3391	-0.0852	0.1687	
School no.1 - School no.6	-0.3335	0.0788	0.4910	
School no.1 - School no.4	-0.1575	0.1447	0.4469	
School no.1 - School no.3	0.1090	0.4480	0.7870	***
School no.6 - School no.5	-1.0915	-0.6636	-0.2357	***
School no.6 - School no.2	-0.5760	-0.1640	0.2480	
School no.6 - School no.1	-0.4910	-0.0788	0.3335	
School no.6 - School no.4	-0.3774	0.0659	0.5093	
School no.6 - School no.3	-0.1000	0.3692	0.8385	
School no.4 - School no.5	-1.0528	-0.7296	-0.4064	***
School no.4 - School no.2	-0.5318	-0.2299	0.0719	
School no.4 - School no.1	-0.4469	-0.1447	0.1575	
School no.4 - School no.6	-0.5093	-0.0659	0.3774	
School no.4 - School no.3	-0.0729	0.3033	0.6795	
School no.3 - School no.5	-1.3907	-1.0329	-0.6750	***
School no.3 - School no.2	-0.8719	-0.5332	-0.1945	***
School no.3 - School no.1	-0.7870	-0.4480	-0.1090	***
School no.3 - School no.6	-0.8385	-0.3692	0.1000	
School no.3 - School no.4	-0.6795	-0.3033	0.0729	

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 REACTIVITY QUESTIONNAIRE-STD 8 AND STD 10 STUDENTS

General Linear Models Procedure
Class Level Information

Class	Levels	Values
School	6	School no.5 School no.4 School no.2 School no.3 School no.1 School no.6

Number of observations in data set = 646

COMPARISON OF DIFFERENT School RESULTS FOR STD 8 QUESTIONNAIRE STD 8 AND STD 10 STUDENTS

General Linear Models Procedure

Dependent Variable: TOTEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	54.546619	10.909324	7.84	0.0001
Error	640	890.722731	1.391754		
Corrected Total	645	945.269350			

R-Square	C.V.	Root MSE	Toteight Mean
0.057705	64.47574	1.1797	1.8297

Source	DF	Type I SS	Mean Square	F Value	Pr > F
School	5	54.546619	10.909324	7.84	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
School	5	54.546619	10.909324	7.84	0.0001

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 QUESTIONNAIRE REACTIVITY - ONLY STD 8 STUDENTS

General Linear Models Procedure

T tests (LSD) for variable: Toteight

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 Confidence= 0.95 df= 405 MSE= 1.321951
Critical Value of T= 1.96584

Comparisons significant at the 0.05 level are indicated by '***'.

School Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
School no.5 - School no.1	0.6208	0.9514	1.2819	***
School no.5 - School no.2	0.6247	0.9616	1.2984	***
School no.5 - School no.6	0.3258	0.9846	1.6433	***
School no.5 - School no.4	0.8305	1.2494	1.6683	***
School no.5 - School no.3	0.9638	1.4369	1.9101	***
School no.1 - School no.5	-1.2819	-0.9514	-0.6208	***
School no.1 - School no.2	-0.2807	0.0102	0.3011	
School no.1 - School no.6	-0.6033	0.0332	0.6697	
School no.1 - School no.4	-0.0849	0.2981	0.6810	
School no.1 - School no.3	0.0439	0.4856	0.9272	***
School no.2 - School no.5	-1.2984	-0.9616	-0.6247	***
School no.2 - School no.1	-0.3011	-0.0102	0.2807	
School no.2 - School no.6	-0.6168	0.0230	0.6628	
School no.2 - School no.4	-0.1005	0.2879	0.6763	
School no.2 - School no.3	0.0290	0.4754	0.9217	***
School no.6 - School no.5	-1.6433	-0.9846	-0.3258	***
School no.6 - School no.1	-0.6697	-0.0332	0.6033	
School no.6 - School no.2	-0.6628	-0.0230	0.6168	
School no.6 - School no.4	-0.4217	0.2649	0.9514	
School no.6 - School no.3	-0.2685	0.4524	1.1733	
School no.4 - School no.5	-1.6683	-1.2494	-0.8305	***
School no.4 - School no.1	-0.6810	-0.2981	0.0849	
School no.4 - School no.2	-0.6763	-0.2879	0.1005	
School no.4 - School no.6	-0.9514	-0.2649	0.4217	
School no.4 - School no.3	-0.3236	0.1875	0.6986	
School no.3 - School no.5	-1.9101	-1.4369	-0.9638	***
School no.3 - School no.1	-0.9272	-0.4856	-0.0439	***
School no.3 - School no.2	-0.9217	-0.4754	-0.0290	***
School no.3 - School no.6	-1.1733	-0.4524	0.2685	
School no.3 - School no.4	-0.6986	-0.1875	0.3236	

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 QUESTIONNAIRE REACTIVITY - ONLY STD 8 STUDENTS

General Linear Models Procedure

T tests (LSD) for variable: Toteight

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 Confidence= 0.95 df= 405 MSE= 1.321951
Critical Value of T= 1.96584

Comparisons significant at the 0.05 level are indicated by '***'.

School Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
School no.5 - School no.1	0.6208	0.9514	1.2819	***
School no.5 - School no.2	0.6247	0.9616	1.2984	***
School no.5 - School no.6	0.3258	0.9846	1.6433	***
School no.5 - School no.4	0.8305	1.2494	1.6683	***
School no.5 - School no.3	0.9638	1.4369	1.9101	***
School no.1 - School no.5	-1.2819	-0.9514	-0.6208	***
School no.1 - School no.2	-0.2807	0.0102	0.3011	
School no.1 - School no.6	-0.6033	0.0332	0.6697	
School no.1 - School no.4	-0.0849	0.2981	0.6810	
School no.1 - School no.3	0.0439	0.4856	0.9272	***
School no.2 - School no.5	-1.2984	-0.9616	-0.624[illegible]	***
School no.2 - School no.1	-0.3011	-0.0102	0.280[illegible]	
School no.2 - School no.6	-0.6168	0.0230	0.6628	
School no.2 - School no.4	-0.1005	0.2879	0.6763	
School no.2 - School no.3	0.0290	0.4754	0.9217	***
School no.6 - School no.5	-1.6433	-0.9846	-0.3258	***
School no.6 - School no.1	-0.6697	-0.0332	0.6033	
School no.6 - School no.2	-0.6628	-[illegible].0230	0.6168	
School no.6 - School no.4	-0.4217	0.2649	0.9514	
School no.6 - School no.3	-0.2685	0.4524	1.1733	
School no.4 - School no.5	-1.6683	-1.2494	-0.8305	***
School no.4 - School no.1	-0[illegible].6810	-0.2981	0.0849	
School no.4 - School no.2	-[illegible].6763	-0.2879	0.1005	
School no.4 - School no.6	-0.9514	-0.2649	0.4217	
School no.4 - School no.3	-0.3236	0.1875	0.6986	
School no.3 - School no.5	-1.9101	-1.4369	-0.9638	***
School no.3 - School no.1	-0.9272	-0.4856	-0.0439	***
School no.3 - School no.2	-0.9217	-0.4754	-0.0290	***
School no.3 - School no.6	-1.1733	-0.4524	0.2685	
School no.3 - School no.4	-0.6986	-0.1875	0.3236	

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 QUESTIONNAIRE
REACTIVITY ONLY STD 8 STUDENTS

General Linear Models Procedure
Class Level Information

Class	Levels	Values
School	6	School no.5 School no.4 School no.2 School no.3 School no.1 School no.6

Number of observations in data set = 411

COMPARISON OF DIFFERENT SCHOOL RESULTS FOR STD 8 QUESTIONNAIRE
ONLY STD 8 STUDENTS

General Linear Models Procedure

Dependent Variable: Toteight

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	75.456528	15.091306	11.42	0.0001
Error	405	535.390187	1.321951		
Corrected Total	410	610.846715			

R-Square	C.V.	Root MSE	Toteight Mean
0.123528	60.12111	1.1498	1.9124

Source	DF	Type I SS	Mean Square	F Value	Pr > F
School	5	75.456528	15.091306	11.42	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
School	5	75.456528	15.091306	11.42	0.0001

Std.8 questionnaire: std 8 and std 10 students only

Analysis Variable : Toteight.

School=School no. 1

N	Mean	Std Dev	Minimum	Maximum
166	1.7710843	1.2192924	0	5.0000000

School=School no.2

N	Mean	Std Dev	Minimum	Maximum
167	1.8562874	1.1836000	0	6.0000000

School=School no.3

N	Mean	Std Dev	Minimum	Maximum
65	1.3230796	0.9203887	0	3.0000000

School=School no.4

N	Mean	Std Dev	Minimum	Maximum
91	1.6263736	1.0290055	0	6.0000000

School=School no.5

N	Mean	Std Dev	Minimum	Maximum
118	2.3559322	1.3108712	0	6.0000000

School=School no.6

N	Mean	Std Dev	Minimum	Maximum
39	1.6923077	1.2804984	0	5.0000000

APPENDIX E1

COMPARISON OF DIFFERENT SCHOOLS RESULTS FOR THE STANDARD 8 REACTIVITY QUESTIONNAIRE

Std.8 questionnaire: Std 8 students only

Analysis Variable : Toteight

Std=8 School=School no. 1

N	Mean	Std Dev	Minimum	Maximum.
127	1.8188976	1.1711975	0	5.0000000

School=School no.2

N	Mean	Std Dev	Minimum	Maximum
115	1.8086957	1.1839249	0	6.0000000

School=School no.3

N	Mean	Std Dev	Minimum	Maximum.
33	1.3333333	0.9242114	0	3.0000000

School=School no.4

N	Mean	Std Dev	Minimum	Maximum
48	1.5208333	0.9890805	0	4.0000000

School=School no.5

N	Mean	Std Dev	Minimum	Maximum
74	2.7702703	1.2112181	0	6.0000000

School=School no.6

N	Mean	Std Dev	Minimum	Maximum
14	1.7857143	1.3114039	0	4.000000

APPENDIX E1

Students t-test

Std 8 & 10 responses to Std 8 questionnaire

Ttest procedure

Variable: totalght

Std	N	Mean	Std Dev	Std Error
8	411	1.91240876	1.22060233	0.06020787
10	235	1.68510638	1.18158569	0.07707815

Variances	T	DF	Prob> abs. T
Unequal	2.3240	500.4	0.0205
Equal	2.3035	644.0	0.0216

For H0: Variances are equal, F' = 1.07 DF = (410,234)
Prob>F' = 0.5837

Chi-Square Test

Std 8 & 10 responses per question to Std 8 questionnaire

Table of Std by Mcq88

Std	Mcq88		
Frequency Percent Row Pct Col Pct	0	1	Total
8	341 52.79 82.97 61.66	70 10.84 17.03 75.27	411 63.62
10	212 32.82 90.21 38.34	23 3.56 9.79 24.73	235 36.38
Total	553 85.60	93 14.40	646 100.00

Statistics for table of Std by Mcq88

Statistic		DF	Value	Prob
Chi-Square		1	6.367	0.012
Likelihood Ratio Chi-Square		1	6.693	0.010
Continuity Adj. Chi-Square		1	5.793	0.016
Mantel-Haenszel Chi-Square		1	6.357	0.012
Fisher's Exact Test	(Left)			7.05E-03
	(Right)			0.997
	(2-Tail)			0.014
Phi Coefficient			-0.099	
Contingency Coefficient			0.099	
Cramer's V			-0.099	

Sample Size = 646

All schools, Std 10
Question 6

Answer	Frequency	Percent
A	62	26.4
B	28	11.9
C	30	12.8
D	68	28.9
*E	43	18.3
X	4	1.7

Question 7

Answer	Frequency	Percent
A	42	17.9
B	71	30.2
*C	79	33.6
D	27	11.5
E	16	6.8

Std 10 responses to Std 8 questionnaire: All schools
Question 1

Answer	Frequency	Percent
A	177	75.3
B	8	3.4
C	1	0.4
*D	16	6.8
E	33	14.0

Question 2

Answer	Frequency	Percent
A	35	14.9
*B	135	57.4
C	13	5.5
D	21	8.9
E	26	11.1
X	5	2.1

Question 3

Answer	Frequency	Percent
A	4	1.7
B	3	1.3
C	127	54.0
D	87	37.0
*E	14	6.0

APPENDIX F1

STD 10 RESULTS FOR STD 10 RATE AND EQUILIBRIUM QUESTIONNAIRE

Std 10 questionnaire

All schools, Std 10's

Question 1

Answer	Frequency	Percent
A	84	35.7
B	36	15.3
C	23	9.8
D	34	14.5
*E	58	24.7

Question 2

Answer	Frequency	Percent
A	29	12.3
B	82	34.9
*C	53	22.6
D	53	22.6
E	17	7.2
X	1	0.4

Question 3

Answer	Frequency	Percent
A	14	6.0
B	70	29.8
C	33	14.0
*D	70	29.8
E	47	20.0
X	1	0.4

Question 4

Answer	Frequency	Percent
A	66	28.1
B	29	12.3
C	48	20.4
D	14	6.0
*E	76	32.3
X	2	0.9

Question 5

Answer	Frequency	Percent
A	83	35.3
B	25	10.6
*C	13	5.5
D	64	27.2
E	50	21.3

APPENDIX F1

School: School no.6, Std 8
Question 4

Answer	Frequency	Percent
*A	7	50.0
B	4	28.6
E	3	21.4

School: School no.6, Std 8
Question 5

Answer	Frequency	Percent
A	3	21.4
B	3	21.4
C	6	42.9
D	1	7.1
*E	1	7.1

School: School no.6, Std 8
Question 6

Answer	Frequency	Percent
A	2	14.3
B	2	14.3
C	5	35.7
*D	3	21.4
E	2	14.3

School: School no.6, Std 8
Question 7

Answer	Frequency	Percent
A	6	42.9
B	1	7.1
*C	3	21.4
D	1	7.1
E	3	21.4

School: School no.6, Std 8
Question 8

Answer	Frequency	Percent
A	1	7.1
B	2	14.3
D	10	71.4
*E	1	7.1

School: School no.5, Std 8
Question 6

Answer	Frequency	Percent
A	3	4.1
B	16	21.6
C	22	29.7
*D	25	33.8
E	8	10.8

School: School no.5, Std 8
Question 7

Answer	Frequency	Percent
A	2	2.7
B	34	45.9
*C	23	31.1
D	5	6.8
E	7	9.5
X	3	4.1

School: School no.5, Std 8
Question 8

Answer	Frequency	Percent
A	6	8.1
B	5	6.8
C	5	6.8
D	23	31.1
*E	35	47.3

School: School no.6, Std 8
Question 1

Answer	Frequency	Percent
A	13	92.9
C	1	7.1

School: School no.6, Std 8
Question 2

Answer	Frequency	Percent
A	1	7.1
*B	10	71.4
C	2	14.3
E	1	7.1

School: School no.6, Std 8
Question 3

Answer	Frequency	Percent
A	2	14.3
C	10	71.4
D	2	14.3

School: School no.5, Std 8
Question 1

Answer	Frequency	Percent
A	59	79.7
*D	3	4.1
E	12	16.2

School: School no.5, Std 8
Question 2

Answer	Frequency	Percent
A	9	12.2
*B	56	75.7
C	1	1.4
D	5	6.8
E	3	4.1

School: School no.5, Std 8
Question 3

Answer	Frequency	Percent
A	4	5.4
B	1	1.4
C	54	73.0
D	9	12.2
*E	6	8.1

School: School no.5, Std 8
Question 4

Answer	Frequency	Percent
*A	46	62.2
B	10	13.5
C	9	12.2
D	4	5.4
E	5	6.8

School: School no.5, Std 8
Question 5

Answer	Frequency	Percent
A	22	29.7
B	2	2.7
C	7	9.5
D	31	41.9
*E	11	14.9
X	1	1.4

School: School no.4, Std 8
Question 4

Answer	Frequency	Percent
	2	.
*A	18	39.1
B	10	21.7
C	12	26.1
D	4	8.7
E	2	4.3

School: School no.4, Std 8
Question 5

Answer	Frequency	Percent
A	15	31.2
B	3	6.3
C	4	8.3
D	20	41.7
*E	6	12.5

School: School no.4, Std 8
Question 6

Answer	Frequency	Percent
A	1	2.1
B	13	27.1
C	27	56.3
*D	2	4.2
E	5	10.4

School: School no.4, Std 8
Question 7

Answer	Frequency	Percent
	1	.
A	8	17.0
B	18	38.3
*C	9	19.1
D	3	6.4
E	9	19.1

School: School no.4, Std 8
Question 8

Answer	Frequency	Percent
A	8	16.7
B	17	35.4
C	3	6.3
D	15	31.2
*E	5	10.4

School: School no.3, Std 8
Question 7

Answer	Frequency	Percent
A	4	12.1
B	21	63.6
*C	4	12.1
D	2	6.1
E	2	6.1

School: School no.3, Std 8
Question 8

Answer	Frequency	Percent
A	1	3.0
B	6	18.2
C	1	3.0
D	20	60.6
*E	5	15.2

School: School no.4, Std 8
Question 1

Answer	Frequency	Percent
A	36	75.0
B	2	4.2
C	1	2.1
*D	4	8.3
E	5	10.4

School: School no.4, Std 8
Question 2

Answer	Frequency	Percent
A	16	33.3
*B	26	54.2
C	1	2.1
D	3	6.3
E	2	4.2

School: School no.4, Std 8
Question 3

Answer	Frequency	Percent
A	5	10.4
B	3	6.3
C	25	52.1
D	12	25.0
*E	3	6.3

School: School no.3, Std 8
Question 1

Answer	Frequency	Percent
A	27	81.8
B	2	6.1
*D	1	3.0
E	3	9.1

School: School no.3, Std 8
Question 2

Answer	Frequency	Percent
A	3	9.1
*B	21	63.6
C	1	3.0
D	6	18.2
E	2	6.1

School: School no.3, Std 8
Question 3

Answer	Frequency	Percent
A	2	6.1
B	1	3.0
C	21	63.6
D	8	24.2
*E	1	3.0

School: School no.3, Std 8
Question 4

Answer	Frequency	Percent
*A	7	21.2
B	5	15.2
C	7	21.2
D	6	18.2
E	8	24.2

School: School no.3, Std 8
Question 5

Answer	Frequency	Percent
A	8	24.2
B	2	6.1
C	10	30.3
D	12	36.4
*E	1	3.0

School: School no.3, Std 8
Question 6

Answer	Frequency	Percent
A	2	6.1
B	12	36.4
C	12	36.4
*D	4	12.1
E	3	9.1

School: School no.2, Std 8
Question 4

Answer	Frequency	Percent
*A	47	40.9
B	13	11.3
C	21	18.3
D	14	12.2
E	18	15.7
X	2	1.7

School: School no.2, Std 8
Question 5

Answer	Frequency	Percent
A	27	23.5
B	2	1.7
C	17	14.8
D	60	52.2
*E	8	7.0
X	1	0.9

School: School no.2, Std 8
Question 6

Answer	Frequency	Percent
A	10	8.
B	22	19.1
C	46	40.0
*D	23	20.0
E	13	11.3
X	1	0.9

School: School no.2, Std 8
Question 7

Answer	Frequency	Percent
A	9	7.8
B	62	53.9
*C	21	18.3
D	14	12.2
E	9	7.8

School: School no.2, Std 8
Question 8

Answer	Frequency	Percent
A	12	10.4
B	28	24.3
C	8	7.0
D	57	49.6
*E	10	8.7

School: School no.1, Std 8
Question 7

Answer	Frequency	Percent
	2	.
A	26	20.8
B	49	39.2
*C	24	19.2
D	17	13.6
E	8	6.4
X	1	0.8

School: School no.1, Std 8
Question 8

Answer	Frequency	Percent
	2	.
A	13	10.4
B	34	27.2
C	8	6.4
D	56	44.8
*E	14	11.2

School: School no.2, Std 8
Question 1

Answer	Frequency	Percent
A	83	72.2
B	2	1.7
C	6	5.2
*D	14	12.2
E	10	8.7

School: School no.2, Std 8
Question 2

Answer	Frequency	Percent
A	16	13.9
*B	67	58.3
C	3	2.6
D	13	11.3
E	14	12.2
X	2	1.7

School: School no.2, Std 8
Question 3

Answer	Frequency	Percent
A	9	7.8
B	5	4.3
C	55	47.8
D	28	24.3
*E	18	15.7

School: School no.1, Std 8
Question 2

Answer	Frequency	Percent
	1	.
A	20	15.9
*B	90	71.4
C	7	5.6
D	3	2.4
E	5	4.0
X	1	0.8

School: School no.1, Std 8
Question 3

Answer	Frequency	Percent
A	10	7.9
C	75	59.1
D	25	19.7
*E	17	13.4

School: School no.1, Std 8
Question 4

Answer	Frequency	Percent
*A	28	22.0
B	53	41.7
C	6	4.7
D	17	13.4
E	22	17.3
X	1	0.8

School: School no.1, Std 8
Question 5

Answer	Frequency	Percent
A	49	38.6
B	9	7.1
C	28	22.0
D	30	23.6
*E	11	8.7

School: School no.1, Std 8
Question 6

Answer	Frequency	Percent
	1	.
A	13	10.3
B	30	23.8
C	31	24.6
*D	38	30.2
E	13	10.3
X	1	0.8