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DO SCHOOL TEXTS PROMOTE THE UNDERSTANDING OF INORGANIC CHEMISTRY QUALITATIVE ANALYSIS?

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This paper describes the analysis of two commonly used secondary chemistry textbooks and two practical workbooks in Singapore to determine if the contents present are consistent with the concepts and propositional knowledge, identified by the authors, as essential for the learning and understanding of O-level qualitative analysis. It was found that none of the textbooks and workbooks explicitly highlighted all the reactions involved in the procedures in qualitative analysis. The omission was likely to give students incomplete or little understanding of qualitative analysis, resulting in students adopting a cookbook understanding of qualitative analysis, resulting in students adopting a cookbook approach to qualitative analysis practical work.

INTRODUCTION

Textbooks are very important in science education as they are generally the sole source of information on the subject for both teachers and students, and influence the curriculum, coverage of content and teaching approaches (Chiang-Soong & Yager, 1993; De Jong, Acampo & Verdonk, 1995; Eltinge & Roberts, 1993; Sanger & Greenbowe, 1997, 1999). In the United State, teachers used textbooks in excess of 90% of the time; students expected science lessons to be centred around textbooks, and parents expressed concern if textbooks were not issued and used for assignments (Chiang-Soong & Yager, 1993).

Since textbooks play such a dominant role in school science, they need to be carefully evaluated (Eltinge & Roberts, 1993) so that textbook learning

is “meaningful, conceptually integrated, and active” (de Posada, 1999, p. 427). Textbook content should be free from ambiguities, alternative conceptions should be presented and information explained, help students to relate new material to that already learnt, and help students to integrate the material presented explicitly in a coherent way. Analysis of textbooks can indicate the procedures, content, sequences and activities that are used in the classroom, trends in science education, and the “pedagogical, psychological, and epistemological positions of textbook authors” (de Posada, 1999, p. 425). Textbooks have been analysed as sources of alternative conceptions (Cho, Kahle & Nordland, 1985; Sanger & Greenbowe, 1999) and for the use of analogy (Curtis & Reigeluth, 1984; Thiele, Ventille & Treagust, 1995). Textbooks have also been analysed to determine the treatment of topics and concepts (Dall’Alba, et.al., 1993; de Berg & Treagust, 1993; de Berg & Greive, 1999; de Posada 1999; Palmer & Treagust, 1996; Shiland, 1997), the treatment of various issues of science literacy and goals of science education (Chiang-Soong & Yager, 1993; Wilkinson, 1999), and how science is portrayed (Eltinge & Roberts, 1993).

Furio, Azcona, Guisasola & Ratcliffe (2000) examined 174 chemistry textbooks and found that the concept ‘mole’ was erroneously presented as chemical mass and/or number of elementary entities instead of amount of substance. Sanger and Greenbowe (1999) analysed ten college-level chemistry texts for examples of statements or drawings that could lead to alternative conceptions in electrochemistry. They found that many illustrations and statements used in the textbooks could be misinterpreted by students. Examples include the use of vague or misleading terms such as ‘ionic charge carries’ and always drawing the anode as the left-hand half-cell. Sanger and Greenbowe (1999) suggest that the extent to which textbooks contain vague, misleading or incorrect material could be used as a basis for textbook selection. Indeed, Cox (1996) reported the replacement of a series of science books in a school because of “an excessive number of needless errors” (p. 23). Stinner (1992) highlighted that textbooks tend to emphasise the logical aspects of science topics and concepts, neglecting the evidential and psychological dimensions. Linn and Songer (1991) believe that textbooks focus on isolated facts and definitions, provide abstract and/or incomplete explanations, and cover too much content in too little depth, preventing “construction of integrated understanding” (p. 891).

METHODOLOGY

Two commonly used approved chemistry textbooks in Singapore secondary schools, RH and JRGB, and two popular chemistry practical workbooks, CNP and LJR, were analysed to compare the concepts and propositional knowledge on qualitative analysis present in the books to that identified by the authors to identify inconsistencies or shortcomings, if any, of the textbooks when used to teach or learn qualitative analysis.

RH: *Chemistry: A new approach* (4th Ed.). (Heyworth, 1994).

JRGB: *Chemistry for 'O' level* (3th Ed.). (Briggs, 1997).

CNP: *Chemistry: A course for 'O' level: Practical workbook. Volume 2.* (Prescott, 1994).

LJR : *Practical chemistry for 'O' level. Volume 2* (2nd Ed.). (Rasanayagam, 1986).

Text, illustrations (drawings and tables), and activities proposed were examined to determine if the propositional knowledge statements given in Figure 1, which the authors defined as the concepts and propositions necessary for the learning and understanding of the General Certificate of Education Ordinary Level (O-level) inorganic chemistry qualitative analysis, were present in the texts. As in the study by de Posada (1999), a questionnaire was developed (Table 1) and used to analyse the textbooks and workbooks. The items in the questionnaire were concerned with the main reactions involved in the identification of cations, anions and gases in qualitative analysis, and the propositional knowledge statements involved in each item also were listed in Table 1.

Figure 1: List of propositional Knowledge statements pertaining to the O-level Qualitative Analysis

1. When a substance ionises in water to produce hydrogen ions, an acid is formed.
2. Hydrogen ions are responsible for the reactions of acids.
3. When a more reactive element is added to a solution of an ionic compound of a less reactive element, a displacement (redox) reaction may occur, forming the less reactive element and the ionic compound of the more reactive element. (Normally reactive metals displace less reactive metals, and reactive non-metals displace less reactive non-metals. However a reactive metal may react with a dilute acid to displace hydrogen and produce the salt of the metal).
4. An acid will react with a carbonate to produce a salt, carbon dioxide and water.
5. An acid will react with a sulphate (IV) to produce a salt, sulphur dioxide and water.
6. An acid will react with a base to produce a salt and water only.
7. When an acid reacts with a metal, an insoluble base, carbonate or sulphate (IV) to form an insoluble salt, the reaction may stop after a while due to the formation of the insoluble salt which coats the solid reactant particles, preventing further reaction with the acid.
8. If an acid is to be added before or after the addition of a barium, silver or lead (II) reagent to an unknown solution, the anion of the acid must be the same as that of the barium, silver or lead (II) reagent respectively. This is to prevent the introduction of an additional anion which may interfere with the reactions.
9. Alkalis are substances which produce hydroxide ions when dissolved in water.
10. Hydroxide ions are responsible for the reactions of alkalis.
11. An alkali will react with an ammonium salt to produce a salt, ammonia and water.
12. An amphoteric oxide/hydroxide is an oxide/hydroxide of a metal which will react with either an acid or an alkali to produce a salt and water.
13. Aqueous ammonia will react with zinc hydroxide, copper (II) hydroxide and silver chloride to produce the respective soluble complex amines.

14. A precipitation/ double decomposition reaction is a chemical reaction which involves the exchange of ions when two or more aqueous solutions of ionic compounds are added together, and results in the formation of a sparingly soluble ionic compound (which precipitates out of the solution).
15. The solubility of a salt in water determines whether it forms a precipitate during double decomposition reactions.
16. If a precipitate is formed due to the formation of an insoluble hydroxide, the colour of the precipitate and whether it reacts with excess aqueous sodium hydroxide or aqueous ammonia identifies the cation.
17. The ease of decomposition of ionic compounds by heat and the types of products formed depends on the reactivity of the metal present in the compound. The greater the reactivity of the metal, the more difficult it is to decompose the compound by heating.
18. Most carbonates decompose on heating to form the oxide and carbon dioxide.
19. Most sulphate (IV) salts decompose on heating to form the oxide and sulphur dioxide.
20. Most nitrate (V) salts decompose on heating to form the oxide, nitrogen dioxide and oxygen.
21. The physical properties of a substance, for example, colour, odour and solubility, may help in the identification of the substance.
22. Oxidation can be defined as
 - a. the gain of oxygen
 - b. the loss of hydrogen
 - c. the loss of electrons
 - d. an increase in the oxidation state
23. Reduction can be defined as
 - a. the loss of oxygen
 - b. the gain of hydrogen
 - c. the gain of electrons
 - d. a decrease in the oxidation state
24. An oxidising agent (oxidant)
 - a. causes the oxidation of another species
 - b. accepts electrons from the species being oxidised
 - c. is reduced

25. A reducing agent (reductant)
 - a. causes the reduction of another species.
 - b. donates electrons to the species being reduced
 - c. is oxidised
 26. Oxidation-reduction (redox) reactions involve simultaneous oxidation and reduction processes.
 27. Oxidising agents are identified through the use of specific reducing agents (e.g. aqueous potassium iodide). Colour changes produced in the reactions indicate the presence of oxidising agents.
 28. Reducing agents are identified through the use of specific oxidising agents (e.g. acidified potassium dichromate (VI) or acidified potassium manganate (VII)). Colour changes produced in the reactions indicate the presence of reducing agents.
 29. When a solid solute dissolves in a liquid solvent, a homogeneous mixture of the solute and the solvent is obtained; the solute can be recovered in its original form simply by removing (e.g. evaporating) the solvent.
 30. A solute dissolves in a solvent because of the interaction among the solute and solvent particles. Generally, in a solution, the attraction between the solute-solvent particles is greater than the attraction between the solute-solute or solvent-solvent particles.
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Table 1
Questionnaire Used To Analyse The Textbooks And Workbooks

Items	Propositional Statements
<i>Identification of cations</i>	
1. Is the formation of precipitates explained? Yes/No. If yes, how?	
a. Exchange of ions.	14
b. Formation of insoluble salt.	15, 16
2. Is the reaction between precipitates and excess alkali explained? If yes, which one?	
a. Reaction between aqueous sodium hydroxide and amphoteric hydroxide.	12, 16
b. Reaction between aqueous ammonia and precipitate.	13, 16
3. Is the reaction between ammonia salt and sodium hydroxide explained? Yes/No.	11
<i>Identification of anions</i>	
4. Is the formation of precipitates explained? Yes/No. If yes, how?	
a. Exchange of ions.	14
b. Formation of insoluble salt.	15
5. Is the reaction between precipitates and acid explained? If yes, which one?	
a. Acid-carbonate.	4
b. Acid-sulphate (IV).	5
6. Is the reaction between silver chloride precipitate and aqueous ammonia explained? Yes/No.	13
<i>Identification of gases</i>	
7. Is the formation of gases explained? Yes/No. If yes, which ones?	
a. Ammonia.	11
b. Carbon dioxide.	4, 18
c. Chlorine.	22, 23, 24, 25, 26
d. Hydrogen.	3
e. Nitrogen dioxide.	20
f. Oxygen.	20, 22, 23, 24, 25, 26
g. Sulphur dioxide.	5, 19

Items	Propositional Statements
8. Is the test for gases explained? Yes/No. If yes, which ones?	
a. Ammonia.	9, 10, 21
b. Carbon dioxide.	1, 2, 14, 15
c. Chlorine.	1, 2, 21, 22, 23, 24, 25, 26, 27
d. Hydrogen.	22, 23, 26
e. Nitrogen dioxide.	1, 2, 21
f. Oxygen.	22, 23, 26
g. Sulphur dioxide.	1, 2, 22, 23, 24, 25, 26, 28

In JGRB, qualitative analysis made up half of the chapter (10 out of 21 pages) on 'Chemical Analysis', the other half being devoted to volumetric analysis. In RH, qualitative analysis made up one section (3 out of 37 pages) on the chapter on 'Acid, bases and salts'. Forty-six pages out of 148 pages were solely devoted to qualitative analysis in CNP, beginning with an introduction, continuing with ten tables, seven activities and ending with 15 worksheets. Almost the whole workbook (120 pages) by LJR was devoted to qualitative analysis and past years' examination questions.

THE TEXTBOOKS

JGRB

There were many tables and flowcharts to help students identify ions and gases in JGRB, but hardly any explanations were given on the reactions behind the tests and the results of the tests. The only reaction described was the reaction between ammonium salts and aqueous sodium hydroxide. There was a statement in the chapter that the reactions of acids and alkalis were described in the preceding chapter on 'Acids, bases and salts'. In the chapter, the only explicit mention of the link between reactions of acids, bases and salts, and qualitative analysis was the statement that reactions between metal ions and alkalis were important in the identification of cations, and to see the relevant section in the following chapter. Exercises given in the chapter focussed on the identification of ions and gases based on experimental data given. Thus the focus of the content on qualitative analysis in JGRB was on procedures to identify the various ions and gases,

and the identification of ions and gases. A summary of the analysis of JGRB and the other texts is given in Table 2. It could be seen that many reactions involved in the identification of cations, anions and gases were not explained, for example, the reactions involved in the formation of precipitates, complex salts, gases, and the reactions involved in the tests for the various gases. Thus, it was likely that students relying solely on JGRB for qualitative analysis would have little knowledge of the concepts and reactions involved in qualitative analysis.

Table 2

Summary Of Analysis Of The Two Textbooks And Workbooks

Items	JGRB	RH	CNP	LJR
<i>Identification of cations</i>				
1. Is the formation of precipitates explained? Yes/No. If yes, how?	n	y	y	y
a. Exchange of ions.		y	y	y
b. Formation of insoluble salt.		y	y	y ¹
2. Is the reaction between precipitates and excess alkali explained? If yes, which one?	n	n	n	n
a. Reaction between aqueous sodium hydroxide and amphoteric hydroxide.				
b. Reaction between aqueous ammonia and precipitate.				
3. Is the reaction between ammonia salt and sodium hydroxide explained? Yes/No.	y	n	n	y ¹
<i>Identification of anions</i>				
4. Is the formation of precipitates explained? Yes/No. If yes, how?	n	y	y ¹	y ¹
a. Exchange of ions.		y	y ¹	y ¹
b. Formation of insoluble salt.		y	y ¹	y ¹
5. Is the reaction between precipitates and acid explained? If yes, which one?	n	n	n	y ¹
a. Acid-carbonate.				y ¹
b. Acid-sulphate (IV).				y ¹
6. Is the reaction between silver chloride precipitate and aqueous ammonia explained? Yes/No.	n	n	n	n

Items	JGRB	RH	CNP	LJR
<i>Identification of gases</i>				
7. Is the formation of gases explained? Yes/No. If yes, which ones?	y	y	y ¹	y ¹
a. Ammonia.	y			y ¹
b. Carbon dioxide.		y	y ¹	y ¹
c. Chlorine.				
d. Hydrogen.				
e. Nitrogen dioxide.			y ¹	
f. Oxygen.			y ¹	y ¹
g. Sulphur dioxide.				y ¹
8. Is the test for gases explained? Yes/No. If yes, which ones?	n	y	n	y ¹
a. Ammonia.				
b. Carbon dioxide.		y		y ¹
c. Chlorine.				y ¹
d. Hydrogen.				
e. Nitrogen dioxide.				
f. Oxygen.				
g. Sulphur dioxide.				

Note: 1 – not explained but students were asked to write the equations involved.

RH

The amount of content on qualitative analysis in RH, though less in comparison with JGRB, had more explanations on the reactions behind the tests and results of the tests. The only table was for the identification of cations and there were no flowcharts for the identification of ions and gases. However, equations were given to explain the reactions for the tests to identify the carbonate, sulphate (VI), chloride and iodide ions, and carbon dioxide. The double decomposition reaction in the tests for cations using aqueous ammonia and sodium hydroxide also was explained, and an ionic equation describing the reaction between calcium ions and hydroxide ions was given as an example. However, the reaction of the precipitates with excess aqueous ammonia or sodium hydroxide was not mentioned, nor thermal decomposition of carbonate, sulphate (IV) and nitrate (V) salts. The reaction of ammonium salts with alkali was discussed in the section on 'Bases and alkalis', while the reactions of carbonate, sulphate (IV) and nitrate

(V) salts were discussed in the chapters on 'Carbon', 'Sulphur' and 'Nitrogen', but no explicit links were made with qualitative analysis. The authors believed that RH provided a better 'understanding' of qualitative analysis compared to JRGB as it provided more explanations of the reactions and procedures involved than JRGB which focused more on the 'doing' of qualitative analysis.

THE PRACTICAL WORKBOOKS

The two practical workbooks, CNP and LJR, as expected, gave a more detailed treatment of qualitative analysis than the two textbooks. The workbooks, which solely emphasised the practical aspects of the O-level syllabus, could afford to devote more material on qualitative analysis than the textbooks. Both workbooks were divided into four main sections and the first section gave some general information on qualitative analysis, with both workbooks having tables on tests for anions, cations and gases. Additional tables and information included the appearance and heating of substances, instructions in the question paper and possible inferences that could be made from the instructions, solubility of salts, and tests for oxidising and reducing agents. There were also many flowcharts on how to identify ions and gases in both workbooks. The second section consisted of introductory experiments to familiarise students with the procedures and tests involved in qualitative analysis; students are required to perform tests for specific substances. The third section of the workbooks required students to identify unknown substances, and finally, past years' examination papers were given in the fourth section. Thus the 'doing' part, how to identify substances, of qualitative analysis was well catered for.

CNP

The only information given on procedures in CNP was in the test for chloride, iodide and sulphate (VI). In the table on the tests for anions, it was stated that dilute acid had to be added in the test for chloride and iodide with aqueous silver nitrate (V) to 'remove any carbonate', and in the test for sulphate (VI) with aqueous barium nitrate (V) or chloride to 'remove any sulphite'. The authors believed that the significance of removing carbonates or sulphite might not dawn upon the students; indeed, interviews with students in an extension of this study showed that they

had little idea why acid had to be added. The worksheets to introduce qualitative analysis to students in CNP had the format of 'Aim', 'Apparatus', 'Materials', 'Procedure', 'Results' and 'Questions'; the theory involved in the activities were not discussed. The procedures given in the worksheets were clear but were not explained. The main emphasis of the worksheets was on the students carrying out the procedures, recording their observation, and making inferences from the observations.

However, in the worksheet on identifying anions, under the test for carbonates, the equation for the reaction between calcium carbonate and dilute hydrochloric acid was asked. The authors took that to count as an explanation for the reaction involved in the test. Equations for the reaction between aqueous potassium iodide and lead (II) nitrate (V), and sodium sulphate (VI) and barium chloride also were asked for in the tests for iodide and sulphate (VI), respectively. Equations also were asked for in the tests for cations using sodium hydroxide. The ionic equation for the reaction between calcium ions and hydroxide ions was given as an example to explain the reaction involved. However, there was no explanation for the identification of ammonium ions using aqueous sodium hydroxide, the reactions between aqueous ammonia and cations, and the reaction of cations with excess alkali. In the worksheets to identify unknown compounds, students were asked to write equations on double decomposition reactions, decomposition of carbonate and nitrate (V), and an acid-carbonate reaction.

In a worksheet to identify substance S5, students were asked to give a balanced chemical equation for S5 dissolving in nitric acid. The authors believed that the word 'dissolving' was incorrectly used in the worksheet, and could lead to alternative conceptions of dissolution (Tan & Koh, 1999).

LJR

In the introductory section, some precautions and practical hints on qualitative analysis were discussed. Students were informed why the test tubes used need to be clean, how to heat substances, precautions to take when detecting gases, how to write observations and deductions. As with CNP, explicit references to reactions involved were generally made by asking students for equations in the various introductory experiments. The equation describing the reaction between carbon dioxide and limewater, and the explanation for the reaction between chlorine and litmus were asked

for in the exercise part of the worksheet on identifying gases. Equations describing the decomposition of certain carbonates, nitrate (V) and sulphates (IV) were required in the worksheet on the heating of substances. In the worksheet on tests for cations, students were told that aqueous ammonia and sodium hydroxide were used to precipitate insoluble hydroxides. Students also had to write a chemical equation for the reaction between an ammonium salt and aqueous sodium hydroxide, and an ionic equation for the reaction between a calcium salt and aqueous sodium hydroxide. Again, no explicit mention was made of the reaction between cations and aqueous ammonia, as well as the reaction of zinc and aluminium ions with excess alkali. In the worksheet on the tests for anions, equations for the reaction between dilute acid and carbonates and sulphate (IV) were required, as were the equations for the precipitation reactions for barium and silver salts with sulphate (IV) and sulphate (VI). Similar equations were asked in the worksheets on the identification of unknowns, but the majority of the questions focussed on the identification of the unknown ions and gases. A worksheet on tests for redox reagents only concentrated on student observation and deduction.

DISCUSSION

From the results above, it can be seen that the two workbooks were better sources of information on qualitative analysis than the textbooks. Many of the reactions involved in qualitative analysis were discussed in the chapters on 'Acids, Bases and Salts' in JGRB and RH, but there were very few explicit links between what was written in the topic 'Acids, Bases and Salts' and qualitative analysis. Students might need such explicit links because they were novices in chemistry and did not have the expertise of textbook authors or teachers to appreciate or understand the reactions involved in the procedures that they carried out. Lacking this knowledge, qualitative analysis is likely to become a mechanical, recipe-driven activity with little meaningful learning.

The two workbooks provided more information on qualitative analysis but through indirect means; many of the reactions involved were highlighted by instructing students to write equations. However, students may be able to write the equations but they may not realise that similar reactions were involved in the same class of reactions or procedures; hence they may not

see the overall picture in qualitative analysis. More explicit content should be given in the introductory sections of the workbooks or the introductory experiments on qualitative analysis to help students relate theory to practice. Even though the workbooks covered more content on qualitative analysis than the textbooks, they still did not cover all the content required to understand O-level qualitative analysis meaningfully. The two areas lacking in the workbooks were the reactions between cations and excess alkali, and the reactions involved in the identification of gases.

CONCLUSION

This paper discussed the analysis of two textbooks and two practical workbooks commonly used in secondary schools in Singapore with respect to material on inorganic chemistry qualitative analysis. Although the textbooks and workbooks were important sources of information for students on qualitative analysis, none explicitly highlighted all the reactions involved in the procedures in qualitative analysis. The omission was likely to give students the idea that qualitative analysis was merely a mechanical activity with few links to the content that they learn in class.

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