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Qualitative analysis practical work – an instructional package

Kim-Chwee Daniel Tan, Ngoh-Khang Goh, Lian-Sai Chia and David F. Treagust

This basic inorganic chemistry qualitative analysis instructional package provides a framework for more meaningful learning of the topic

Qualitative analysis (QA) practical work at the grade 9 and 10 levels (14–17 years-old) in Singapore involves carrying out procedures given in worksheets to identify anions, cations and gases as specified in the syllabus (UCLES, 1996), and/or to deduce properties of unknown substances. Previous studies (Tan *et al.*, 2001, 2002) have shown that students do not like QA practical work, find it difficult to understand and to carry out, and cannot link it to the theory they learn in their classroom chemistry lessons; they fail to see QA as practical work based on the many concepts and reactions that they learn in the topic 'acids, bases and salts'.

Teachers normally begin teaching qualitative analysis by reviewing the reactions involved and demonstrating some procedures that the students need to carry out. Using commercially available workbooks or teacher-prepared worksheets, students then do a series of tests for the various cations, anions, gases, oxidising and reducing agents. After they are familiar with the tests, students are given past years' examination questions which ask them to determine the unknown ions present in given samples or to deduce the properties of unknown substances. The students concentrate on carrying out the procedures given and getting the 'correct' observations. This is because they are assessed solely on their written reports in their 90-minute national end-of-year practical examinations in grade 10 (15–17 years-old), and, for QA, their observations account for most of the marks. Thus, getting good results mainly requires getting the right answers, and students can be trained to do the experiments and to write the right answers since the experiments in the examinations do not vary much. It is no surprise that drill and practice in QA practical work is prevalent in Singapore schools (Goh, Toh and Chia, 1987) – it demands little cognitive effort but pays off handsomely in terms of results.

ABSTRACT
Previous research has shown that grade 10 students in Singapore find qualitative analysis practical work difficult to understand and carry out, and unrelated to the theory they had learned in class. This article describes a teaching package developed explicitly to teach the concepts, processes and thinking skills involved in qualitative analysis.

The qualitative analysis teaching package

The Qualitative Analysis Teaching Package (QATP) has been developed by the authors to teach the concepts, processes and thinking skills required to help students understand better what they are doing during QA practical work. The theoretical foundations of the teaching package centre mainly on the studies by Woolnough and Allsop (1985), Driver and Oldham (1986), Goh *et al.* (1987) and Volet (1991). The key factors underpinning the design and development are:

Experience. To allow students to have tacit knowledge of the phenomena, reagents and apparatus, and to construct explanations of the phenomena.

Exercise. To allow students to be proficient in manipulative, observational and inferential skills.

Application. To allow students to apply what they have learnt by planning, executing and evaluating experiments to identify unknown samples.

Thinking skills. To allow students to learn the thinking required in qualitative analysis, to observe how an expert (the teacher) analyses worksheets and carries out the procedures, and to model the teacher.

Sections on the testing of cations are given below to illustrate the key features of the QATP.

Testing cations

Experiencing cations

Box 1 describes a sequence of reactions to allow students to experience precipitate formation involved in the tests for cations using aqueous ammonia, and the disappearance of certain precipitates when excess aqueous ammonia is added. This is to help them understand the reactions involved in the identification of many cations: formation of insoluble hydroxide through exchange of ions, and reaction of the hydroxides with excess aqueous ammonia to form soluble complex salts. Students learn the ion exchange reactions in the topic 'Acids, bases and salts', but formation of complex ammines is not in the syllabus. However, students do learn that amphoteric hydroxides react with excess aqueous sodium hydroxide to form complex salts (but they do not need to know the chemical equations involved), and these reactions are similar to complex ammine formation. Students are required to think about the chemical phenomena, write down their thoughts and discuss them with their classmates. They will listen to the teacher's explanations, compare them with their own ideas and try to resolve any differences or any areas that they do not understand. As students have difficulty in relating what they learn in class to the QA practical work (Tan *et al.*, 2001), teachers need to make the links explicit for their students. To help students understand ion exchange reactions leading to the formation of precipitates at the micro-level, computer animation is used. Firstly, students see an animation of the particles of a soluble salt being bombarded by water molecules and leaving with the water molecules, leading to the 'disintegration' of the salt. They also see the behaviour of an insoluble salt in water, where the water molecules cannot 'pull' the particles away from the salt. Once the concept of solubility is understood, students then go on to animations showing two solutions being mixed resulting in the exchange of ions and formation of an insoluble compound (see the screen captures in Figures 1, 2 and 3). Students are also encouraged to make their own insoluble salts and amphoteric hydroxides to help them apply and gain confidence in their knowledge.

Box 1 Experiencing formation of precipitates and reaction of a precipitate with excess aqueous ammonia

1 Sodium chloride + aqueous ammonia
Experience no visible reaction.

2 Iron(III) solution + aqueous ammonia
- a Experience precipitation and compare with **1** above.
- b Find out that the precipitate is insoluble in excess water or aqueous ammonia.
- c Learn the reason for the formation of insoluble salt – exchange of ions resulting in the formation of an insoluble salt. This is taught in the topic 'Acids, bases and salts'.
- d Computer animation is used to illustrate the exchange of ions resulting in the formation of an insoluble salt.
- e Make a precipitate of their choice by consulting the list of insoluble salts given in the textbook and deciding which solutions to use in order to get the precipitate.

3 Copper(II) solution + aqueous ammonia
- a Experience a precipitate which is insoluble when water is added but disappears when excess aqueous ammonia is added – experience the characteristic deep-blue solution which results.
- b Learn that the deep-blue solution results from the copper(II) precipitate reacting with the excess aqueous ammonia – complex salt formation.
- c Make another precipitate which reacts with excess aqueous ammonia.

Exercises on the testing of cations

Box 2 outlines the manipulative, observational and recording skills that students need for testing cations. They are allowed to carry out procedures as many times as necessary until they are proficient in them. Practical work is not merely for students to acquire laboratory skills: rather, students need to master certain skills in order to carry out the practical work successfully (Hodson, 1990). Students are also asked questions on why certain procedures have to be carried

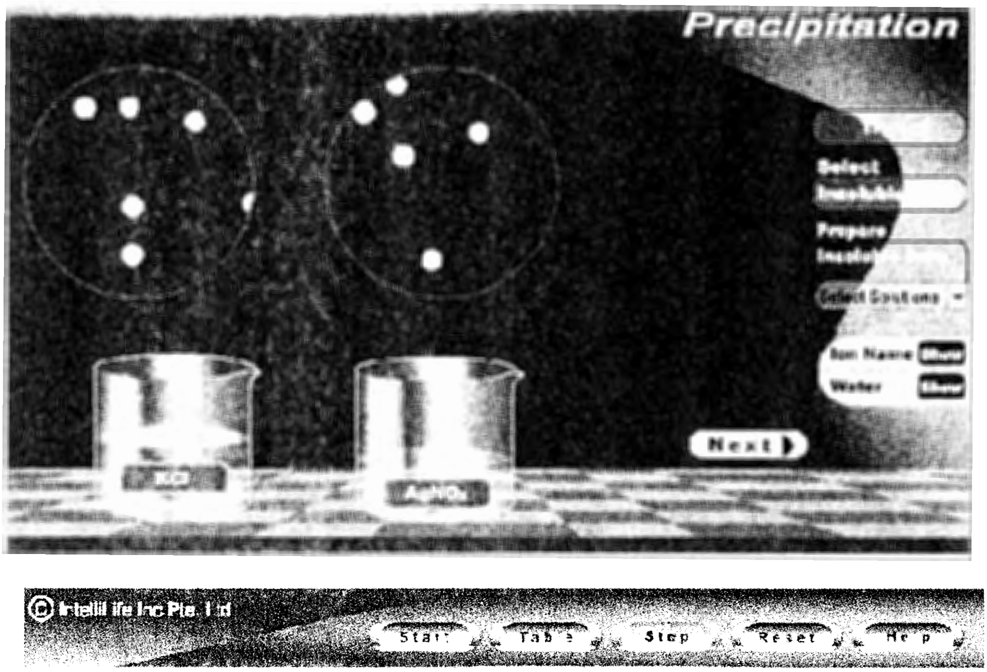

Figure 1 Screen capture showing the solute particles in two solutions (without the water molecules). (Reproduced with permission from Intellilife Inc. Pte. Ltd.)

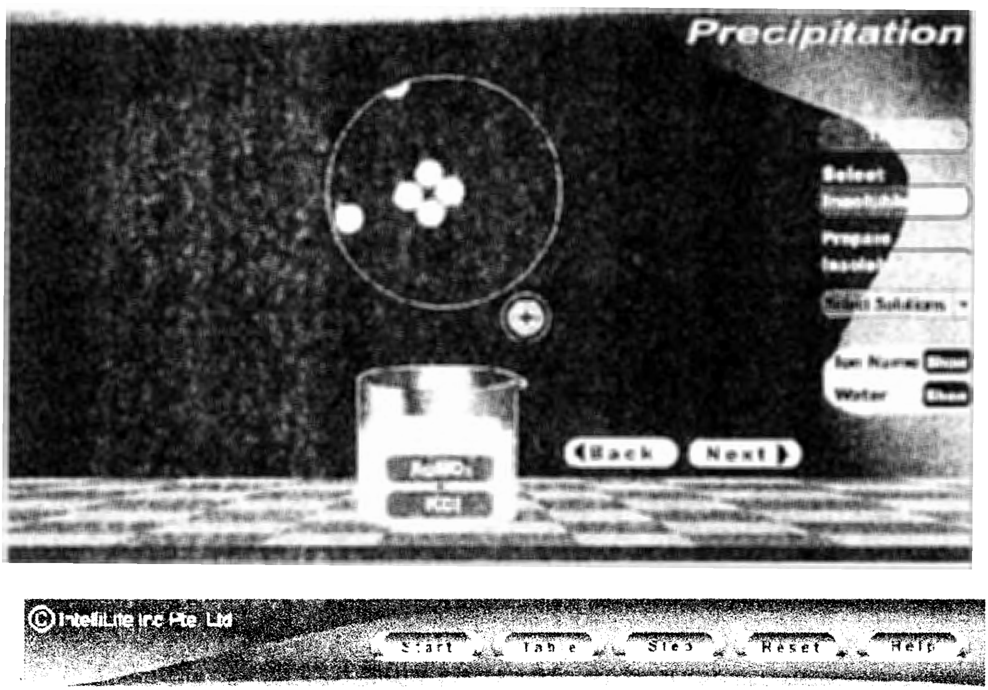

Figure 2 Screen capture showing formation of an insoluble salt. (Reproduced with permission from Intellilife Inc. Pte. Ltd.)

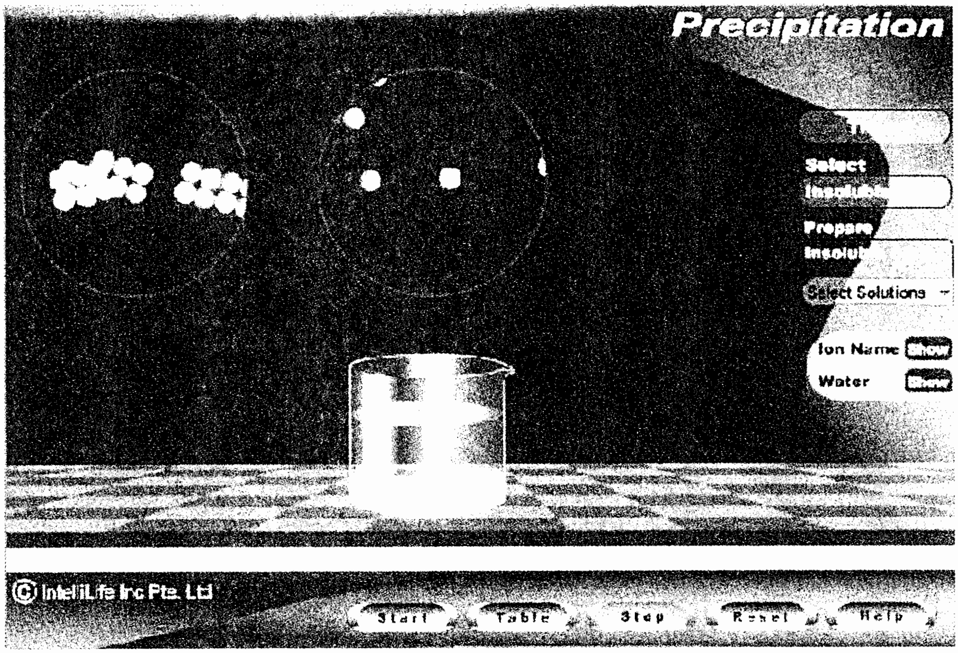

Figure 3 Screen capture showing precipitate settling to the bottom of the beaker. (Reproduced with permission from Intellilife Inc. Pte. Ltd.)

out in a certain way; for example, why they are supposed to add only two drops of aqueous sodium hydroxide initially in the test for cations. These questions are to ensure that they understand the procedures so that they will take care to adhere to them, as well as link the procedures with the knowledge that they learn in class. Bryce and Robertson (1985) warned that many students do not master the basic skills required in practical work. Thus, checklists are used to highlight the skills and important procedures in qualitative analysis that the students need to practise and master, and to allow students to evaluate themselves and their peers. An average class in Singapore has 35 to 42 students, so self- and peer-evaluation are important as the teacher may not have sufficient time to check on all the students.

Applying the knowledge and skills

After they have undergone the experience and exercise sections, students are given unknown solutions and have to determine the cations present without any instructions. Students are given little, if any, opportunity to plan experiments because this is not required in the present practical examinations. Thus, in planning experiments, they will apply what they have learned, and hopefully increase their confidence in the knowledge and skills that they have acquired. Schauble, Klopfer, and Raghavan (1991) believe that students will start to try to understand the relevant concepts involved in experiments, instead of merely focusing on results, when they become aware that the experiments require analytic or extended reasoning; the aim of the application activities is to provide such opportunities.

Thinking during practical work

In the practical examinations, students are required to carry out the procedures given and record their observations. To carry out the procedures meaningfully, students need to ask themselves:

- what the procedures are for;
- what reactions will occur;
- what results are expected;
- what further preparations are required before carrying out the procedures, for example, preparing to test for gases which can be evolved (e.g. ammonia when aqueous sodium hydroxide is added to ammonium salts).

This step-by-step analysis of procedures helps students to learn the thinking required in QA practical work. The teacher is also expected to show students how they analyse a worksheet or practical examination paper and how the analysis guides the execution of

Box 2 Skills required for the testing of cations

1 Aims

You will learn to:

a Put the appropriate amount of the zinc solution to be tested into a test-tube.

b Add a small amount of aqueous sodium hydroxide to the zinc solution.

c Add aqueous sodium hydroxide until it is in excess.

d Shake the mixture after each addition of aqueous sodium hydroxide.

e Record your observations.

2 Skills to be practised

a **Solution to be tested.** When you put the zinc solution into a test-tube, you should add until it just covers the hemisphere at the bottom of the test-tube. Why?

b **A small amount of reagent.** When you add a small amount of aqueous sodium hydroxide, you should add about two drops and shake the mixture thoroughly (by shaking the test-tube or using a glass rod to stir). Why?

c **Excess reagent**. When you add aqueous sodium hydroxide, you should add 1 cm height portions at a time, shaking the mixture thoroughly each time until the mixture reaches about 2 cm from the top of the test-tube. If there is a need to, pour away three-quarters of the content of the test-tube and continue adding as described.

3 Practice and checklist

Practise adding aqueous sodium hydroxide to aqueous zinc chloride until you can do it well.

Items	I am able to:	My partner is able to:
Put the solution to be tested into a test-tube.		
Add a small amount of reagent to the test-tube.		
Add reagent until excess.		
Shake the mixture thoroughly each time a reagent is added.		

4 What to observe and how to record your observation

a You need to determine whether a precipitate is formed when a small amount of reagent is added.

b If a precipitate is obtained, record its colour:

e.g. *A white precipitate is obtained.*

c If there seems to be no reaction, then write:

No visible reaction.

d If you are instructed to add a reagent until in excess or add a reagent until no more change occurs (which means the same thing), take note what happens to the precipitate:

(i) If the precipitate disappears, record it and the colour of the solution formed:

e.g. *The white precipitate disappears and a colourless solution is obtained.*

The blue precipitate disappears and a deep-blue solution is obtained.

(ii) If there seems to be no reaction, then write:

There is no visible reaction, the white precipitate remains.

e To determine the colour of a precipitate in a coloured liquid, you have to allow the precipitate to settle and pour away the liquid. Why? An alternative would be to filter off the precipitate.

What is the colour of the precipitate formed in the reaction between aqueous copper(II) sulfate(VI) and aqueous barium chloride?

the procedures; students will see the thinking being put into practice by an expert and this provides a model for them to emulate. The students are required to analyse some worksheets or past years' examination questions in a similar way to give them more practice in the use of the thinking strategies and to allow them to reflect on their understanding. In the future, they are expected to analyse the worksheets or examination questions before starting on the experiments.

A preliminary study

A preliminary study of the QATP was conducted in one secondary school in November 1999, during the end-of-school-year holidays. Students attended lessons for three-and-a-half hours a day for six days. The results of the study showed that the 84 students who were taught qualitative analysis using the QATP scored significantly higher on a two-tier multiple-choice test than the 915 students who were not taught using the package (Tan *et al.*, 2002). The five teachers who observed the trial of the QATP found the package very structured and comprehensive, and believed that students taught using the package would gain a greater understanding of qualitative analysis. The teachers liked the computer animation and felt that it would help students to understand ion exchange reactions and precipitation. They also felt that the checklists were useful for students to evaluate their mastery of the manipulative skills required. However, the teachers felt that carrying out the complete package requires too much time, and that for the less academically-inclined students the package might be too extensive and even overwhelming. Overall, the teachers realised the advantages of the QATP, but would like to customise it to their needs. Thus, more work is required to refine and customise the QATP to the needs of different students, and more rigorous experimental trials are required to determine its efficacy.

Conclusion

To carry out QA practical work meaningfully, students need to:

understand concepts involved in QA (these are the **experiences** referred to);

practise and master the process skills (these are the **exercises** referred to);

plan and conduct experiments (these are the **applications** referred to), and

analyse the procedures given in worksheets (these are the **thinking strategies** referred to).

Teachers, as the experts, need to make explicit the requirements of QA, model the appropriate behaviours and strategies, and monitor the students' learning in the practical sessions. The QATP provides the necessary framework for these as well as more meaningful learning of the concepts and reactions in 'Acids, bases and salts'.

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