Title	Thinking and Understanding in Qualitative Analysis Practical Work.
Author(s)	Daniel Tan Kim Chwee, Goh Ngoh Khang, Chia Lian Sai and David F. Treagust
Source	*Teaching and Learning, 23*(1), 69-75
Published by	Institute of Education (Singapore)

Teaching and Learning, Vol. 23, No. 1 (June 2002) pp. 69–75

Thinking and Understanding in Qualitative Analysis Practical Work

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

Abstract

Students find qualitative analysis practical work difficult and are often uncertain about what they are doing in the laboratory. Students need to have tacit knowledge of the phenomena and reagents involved in qualitative analysis to understand the reactions that occur and the results that they get doing the experiments. Teachers also need to make explicit the links between the theory that students learn in class and the practical work that students do. In addition, teachers need to model the metacognitive strategies that students need in qualitative analysis practical work.

Introduction

Qualitative analysis practical work in Secondary Three and Four in Singapore involves carrying out procedures given in the worksheets to identify anions, cations and gases as specified in the O-level syllabus, and/or to deduce properties of unknown substances. 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 as specified in the syllabus. After they are familiar with the tests, students are given past years' examination questions to determine the unknown ions present in the given samples or to deduce the properties of the unknown substances.

Throughout the series of practical sessions, students need only follow instructions given in the worksheets, and seldom are required to think about or understand what they are doing. This is because the students are assessed solely on their written reports in their 90-minutes national end-of-year practical examinations, and for qualitative analysis, the students' 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 qualitative analysis practical work is prevalent in Singapore schools (Goh, Toh, & Chia, 1987) – it demands little cognitive effort but pays off handsomely in terms of results as illustrated by a teacher's comments:

> *We have to effectively drill them paper after paper to get them used to certain questions and the format of the examination. So we do a lot of past years' examination questions just to gear them towards the requirements of the examination. We gear them towards writing the 'correct' observations and this will give them the marks. In fact if they follow whatever we tell them to do, they'll do well.*

However, Tan *et al.* (2001) found that students had difficulty understanding what they do in qualitative analysis practical work. This is illustrated by the following excerpts of interviews between the interviewer (I) and students S7, S8, S25 and S26:

S7 : *No, I think the main thing is that we don't know what we are testing for...that's the main thing.*

S8 : *Yes...throughout the experiment. If it happens that you did not do the test properly and the results are not what...what you are supposed to obtain, you wouldn't know it. Whereas if you knew what you are testing for, then you will expect a certain result...so if you get something that is different from the (expected) results, you know that you did it wrongly. But usually we don't know that.*

S25: *If you add a reagent like sodium hydroxide...I won't be sure...what cation or anion I am testing for.*

I: *What do you mean you wouldn't be sure?*

S26: *I think she means like we won't know what we are testing for... we always do this thing [the experiments] blindly [without much thought] and then at the end when we have to make some...deductions...then we'll guess...or refer to our qualitative analysis (QA) handbook.*

Teachers also commented that students often were uncertain about what they were doing in the laboratory and would approach them for help without making the effort to think for themselves (Tan, 2000).

Understanding and Thinking in Qualitative Analysis

To help students to understand what they are doing during practical work, Woolnough and Allsop (1985) suggest that students should be allowed to gain tacit knowledge of the phenomena, reagents and apparatus. Providing the tacit knowledge that is involved in qualitative analysis will help students to construct explanations about the procedures that they carry out, the reactions that occur, and the results that they get. Students also need to learn to think when doing qualitative analysis and teachers have an important role to play here. Teachers need to model how they think and monitor what they do (Schraw, 1998) when they carry out qualitative analysis experiments.

Experience

Students need to be given the opportunity to be acquainted with phenomena resulting from the reactions in qualitative analysis. For example, students need to observe colour changes, formation of precipitates and gases, and take note of the odours of gases evolved. Teachers can then explicitly introduce to the students the reactions involved to link what they have learned in class with the procedures that they carry out in qualitative analysis, the reactions that occur, and the results that they get. The inability to relate qualitative analysis theory to practical work seems to be the main weakness of many students (Tan, *et al.*, 2001).

Appendix 1 describes a sequence of reactions to allow students to experience precipitate formation involved in the tests for cations using aqueous sodium hydroxide, and the disappearance of certain precipitates when excess aqueous sodium hydroxide 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 amphoteric hydroxides with excess sodium hydroxide to form complex salts. Students learn these reactions in the topic 'Acids, Bases and Salts', but have difficulty in making the links between what they learn in the classroom and what they do in the laboratory. Thus, teachers need to make the links explicit for their students. To help students understand the phenomena at the micro-level, computer animation could be used – the use of such computer animation by Tan (2000) in qualitative analysis lessons received favourable comments by the five teachers who observed the lessons. Students also are encouraged to make their own insoluble salts and amphoteric hydroxides to help them apply and gain confidence in their knowledge.

Metacognitive strategies

Students need to understand, be aware of, and monitor what they are doing in qualitative analysis practical work. In addition to knowing what procedures to use to test for a given ion or gas and how to execute the procedures, students also need to know why these procedures are required, what reactions can occur, what results to expect, and what further preparations are required before carrying out the procedures. This is seldom emphasized in schools. The metacognitive strategy required for testing gases is illustrated in Appendix 2. This is in response to the finding by Tan (2000) that students find testing of gases difficult.

I : *OK...now, do you find any aspects of QA difficult?*
S5 : *Doing the tests.*
S6 : *Yes...when there's a gas.*
I : *Why do you say that?*
S6 : *Because...you have so many gases and then there's...different tests for each gas...so if you do the wrong test for that gas...then you have to repeat it [keep doing different tests] and...you just keep doing it until you find out [reach the correct test for the gas]*

I : *Why is testing of gases difficult?*
S15: *There are many different tests...so you don't know which type to use...or may be this type may not confirm what gas it is.*

I : *So can I say that you're not too sure of the reaction that has occurred?*
S10: *Yes...sort of.*
S11: *I mean it's like you're doing blindly...you don't know whether to do the hydrogen gas test or the carbon dioxide test. If you do the carbon dioxide test, you can't do the hydrogen test you see, but then it may not be hydrogen or it may not be carbon dioxide. So you may be directing hydrogen gas to limewater instead but that doesn't do anything. But by then you can't put in the glowing splint...er... lighted splint. You really don't know what is...coming out.*

Students need to be aware that some procedures can result in the evolution of gases and that additional preparation is required before carrying out the procedures. For example, if a procedure calls for the addition of a dilute acid to the unknown solution, the student needs to realize that if the unknown contains a carbonate or sulphate(IV) anion, it will react with the acid to form carbon dioxide or sulphur dioxide. Thus, the student needs to ensure that he/she has a test tube containing limewater and a paper soaked with acidified potassium dichromate (VI) or potassium manganate(VII) ready before adding the acid to the unknown. To realise that a gas is produced when he/she sees effervescence is usually too late – all the gas may have escaped by the time preparations are made to test it. In addition, the student needs to realise that other gases such as oxygen, hydrogen and ammonia will not be liberated in the procedure, so there is no need to test for these gases. Many students do not seem to have such awareness of the procedures in qualitative analysis practical work (Tan, 2000).

The teacher has an important role to play in the modeling of metacognitive strategies (Schraw, 1998). He/she needs to show students how to analyze the procedures given in a qualitative analysis worksheet or examination paper, that is, how to determine what the objectives of the procedures are, what results to expect, and what preparations to make. He/She has to carry out the procedures and show how the analysis guides the execution of the procedures; the students see the metacognitive strategies put into practice by an expert and this provides a model for them to emulate. The students should then be required to analyse some worksheets or past years' examination questions in a similar way to give them practice in the use of the metacognitive strategies and to allow them to reflect on their thinking. After the practice, students should be encouraged to carry out the analysis of procedures before doing any experiment, and the awareness of what they are doing should flow from the analysis.

Conclusion

To do meaningful qualitative analysis practical work, students need to have tacit knowledge of the phenomena and reagents involved in qualitative analysis, understand the procedures and reactions, and learn the necessary metacognitive strategies. Teachers, as the experts, need to make explicit the links between the theory that the students learn in class and the experiments that students do in qualitative analysis practical work, as well as model the appropriate strategies.

Dr Daniel Tan is an Assistant Professor in the Science and Technology Education Academic Group, National Institute of Education, Nanyang Technological University.

Dr Goh Ngoh Kang is an Associate Professor and Deputy Head of the Science and Technology Education Academic Group, National Institute of Education, Nanyang Technological University.

Dr Chia Lian Sai is an Associate Professor in the Science and Technology Education Academic Group, National Institute of Education, Nanyang Technological University.

Dr David Treagust is a Professor of Science Education in the National Key Centre for School Science and Mathematics, Curtin University of Technology.

References

Goh, N.K., Toh, K.A., & Chia, L.S. (1987). *The Effect of Modified Laboratory Instruction on Students' Achievement in Chemistry Practicals.* Singapore: Institute of Education.

Schraw, G. (1998). "Promoting general metacognitive awareness." *Instructional Science*, **26**, 113–125.

Tan K.C.D. (2000). *Development and Application of a Diagnostic Instrument to Evaluate Students' Conceptions of Qualitative Analysis.* Unpublished Ph.D. thesis. Curtin University of Technology.

Tan, K.C.D., Goh, N.K., Chia, L.S., & Treagust, D.F. (2001). "Secondary students' perceptions about learning qualitative analysis in inorganic chemistry." *Research in Science and Technological Education*, **19**(2), 223–234.

Woolnough, B., & Allsop, T. (1985). *Practical Work in Science.* Cambridge: Cambridge University Press.

Appendix 1: Experiencing precipitation and reaction of a precipitate with excess aqueous sodium hydroxide

1. **Sodium chloride + aqueous sodium hydroxide**
   Experience no visible reaction.

2. **Iron(III) solution + aqueous sodium hydroxide**
   a. Experience precipitation and compare with 1 above.
   b. Find out that the precipitate is insoluble in excess water or aqueous sodium hydroxide.
   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. Use computer animation 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. **Zinc solution + aqueous sodium hydroxide**
   a. Experience a precipitate which is insoluble when water is added but disappears when excess sodium hydroxide is added.
   b. Learn the reason for the precipitate reacting with the excess aqueous sodium hydroxide – amphoteric hydroxides and complex ion formation. This is also taught in the topic 'Acids, Bases and Salts'.
   c. Make another precipitate which reacts with excess sodium hydroxide.

Appendix 2: Metacognitive strategy required for testing gases

A. Introduction

1. Gases are frequently produced during reactions in QA.
2. Identifying the gases evolved gives clues to the identity of the substances present in an unknown sample.
3. Testing of gases should be done in a logical, systematic and well-prepared manner.
   a. You need to be able to determine whether a certain procedure will result in the formation of gases.
   b. You need to prepare the necessary apparatus and reagents before you carry out the procedure (why?).
   c. You need to be aware of other clues such as colour and odour of the gases.

B. Procedures which may result in the liberation of gases

1. Addition of dilute acid to an unknown sample
2. Addition of an oxidising agent
3. Addition of aqueous sodium hydroxide (especially if the procedure also states gentle heating)
4. Heating of samples

In all the above procedures, you need to ask yourself:
   a. What gases can be evolved?
   b. How do I prepare to test for these gases?
   c. What results do I expect?