A CROSS-AGE STUDY ON THE UNDERSTANDING OF THE REACTIONS INVOLVED IN BASIC INORGANIC CHEMISTRY QUALITATIVE ANALYSIS

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This cross-age study sought to determine the extent of secondary students' (14-17 years old), junior college students' (16 to 19 years old), and graduate trainee-teachers' conceptions of the reactions involved in the testing of cations and anions in basic secondary qualitative analysis. The results showed that many of the participants in the study had little understanding of the reactions involved, and that alternative conceptions were prevalent among all groups of participants. The authors believe that the lack of understanding of the reactions involved in qualitative analysis is due to the requirements of the present qualitative analysis practical work assessment system which mainly emphasizes students' observational skills.

INTRODUCTION

Qualitative analysis (QA) practical work requires students to carry out a series of procedures using chemicals, apparatus and appropriate techniques, observe and record what happens, and make inferences based on their observations. QA is a difficult topic for secondary chemistry students (Tan, Goh, Chia, & Treagust, 2001), possibly because of the content of the topic (White, 1994), the lack of appropriate frameworks (Tasker & Freyberg, 1985; Duit & Treagust, 1995), the lack of cognitive strategies (Gunstone, 1994; Wittrock, 1994), cognitive overloading (Johnstone & Wham, 1982; Nakhleh and Krajcik, 1994) and the lack of mastery of process skills (Goh, Toh & Chia, 1987; Herron, 1996). The content framework of basic secondary QA (Tan, in press) is outlined in Figure 1.

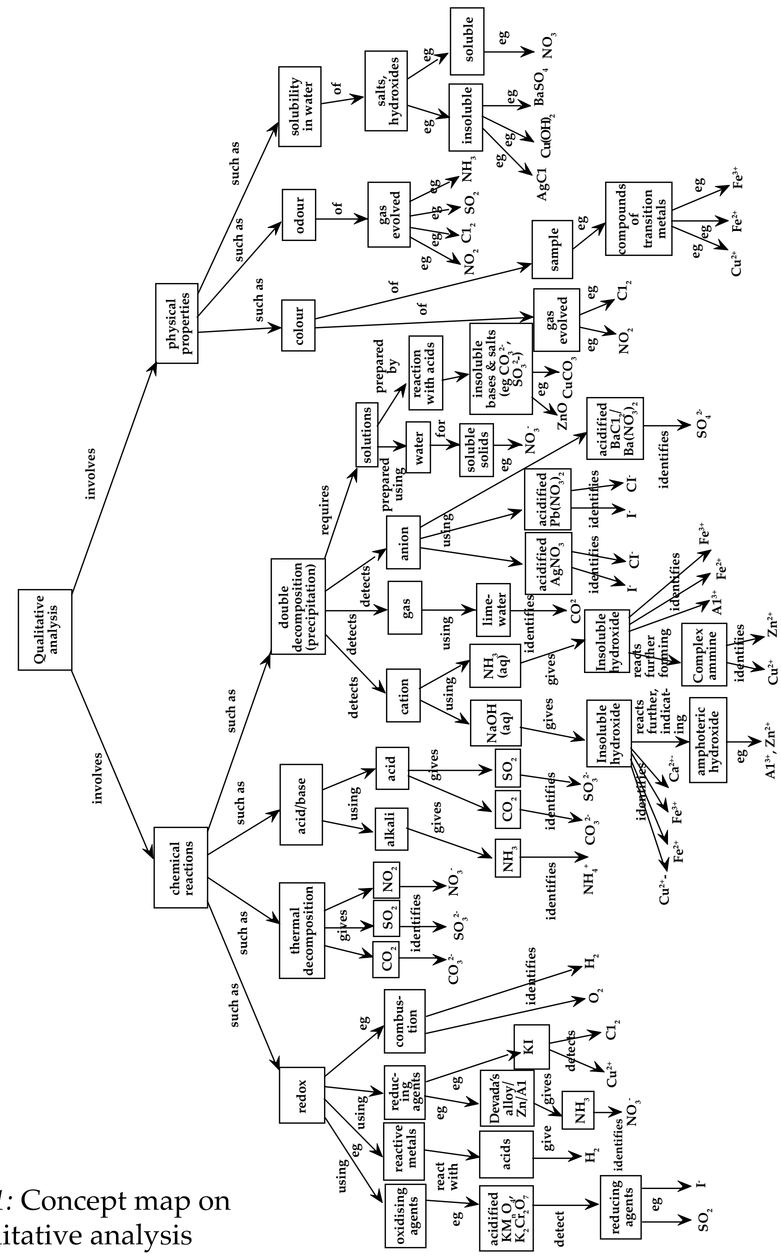

Figure 1: Concept map on qualitative analysis

PURPOSE

This study sought to determine the extent of secondary (Grade 10) students' (15 to 17 years old), junior college (Grade 11 and 12) students' (16 to 19 years old), and graduate trainee-teachers' understanding and alternative conceptions of ion-exchange and acid-salt reactions, and complex salt formation involved in basic secondary QA. A two-tier multiple choice diagnostic instrument, the Qualitative Analysis Diagnostic Instrument (QADI) (Tan, Goh, Chia, & Treagust, 2002) was used in the study. Examples of items in the QADI are given in the Appendix. This comparison was conducted to examine the retention of the alternative conceptions on qualitative analysis over time (Birk & Kurtz, 1999). Cross-age studies are subjected to the error of comparing nonequivalent populations, but are more easily accomplished and have been used in previous studies on student understanding of science concepts (eg., Abraham, Williamson, & Westbrook, 1994; Birk & Kurtz, 1999).

METHOD AND PROCEDURES

The participants

The QADI was administered to 915 secondary students from 11 secondary schools, 360 junior college students from three junior colleges, and 181 graduate trainee-teachers. All the secondary and junior college students took chemistry as a subject, and had undergone a series of QA practical sessions. The junior college students were doing more advanced QA practical work than the secondary students as they were studying chemistry at a more advanced level. All the trainee-teachers took chemistry at the secondary and junior college levels, and many had university degrees in chemistry, material science or chemical engineering. These trainee-teachers were learning to teach secondary chemistry as part of their Postgraduate Diploma in Education course.

Administration and scoring of the QADI

The participants were instructed to answer the items in the QADI without any discussion. A data sheet containing notes on QA was provided with the QADI for all participants to refer to during the test. There was no time restriction for the test, and on the average, participants took between 45 to 60 minutes to complete the QADI. The participants' answer sheets were marked using an optical mark reader, and their results were analysed using SPSS version 9 (SPSS, 1999). Each item was considered to be correctly answered if a participant correctly responded to both parts of the item (Peterson, Treagust & Garnett, 1989).

RESULTS AND DISCUSSION

Test statistics

Test statistics for the various groups are given in Table 1. The lowest mean score was 30% (Grade 10 students) and the highest mean score was 51% (trainee-teachers). A one-way analysis of variance (ANOVA) was conducted to determine the effect of educational level on the scores showed that the mean total scores across educational levels were statistically significantly different ($p = .000$), (Table 2). A post-hoc pairwise multiple comparisons analysis (Tamhane) showed that results of the trainee-teachers (TT) are significantly better ($p < 0.01$) than that of the junior college (JC) and secondary (S) students, and that the results of the junior college students are significantly better ($p < 0.01$) than that of the secondary students (TT > JC > S). This result was expected as graduate trainee-teachers had a minimum of six years of formal chemical education, the junior college students between three to four years, and two years for the secondary (S) students. Thus, it was possible to conclude that understanding of basic qualitative analysis concepts as measured by the QADI increased with educational level.

Table 1
Descriptive Statistics for the Three Educational Level Groups to Whom the QADI was administered

	S	JC	TT
No. of cases	915	360	181
No. of items	19	19	19
Mean (Standard deviation)	5.8 (3.3)	8.1 (3.7)	9.6 (4.6)
Median / Mode	5.0 / 5	8.0 /9	10.0 /11
Minimum / Maximum	0 /18	1 /18	1 /19

Note: S - group of Grade 10 students
JC - group of junior college students
TT - group of graduate trainee-teachers

Table 2
Comparison of the Different Educational Level Groups for Menu Scores on the QADI Using an Analysis of Variance

	Sum of Squares	df	Mean Square	F value	p value
Between Groups	3042.11	2	1521.05	119.54	.000
Within Groups	18487.62	1453	12.72		
Total	21529.73	1455			

Alternative conceptions

The alternative conceptions of the secondary students, junior college students, and trainee-teachers of the ion-exchange and acid-salt reactions, and complex salt formation involved in the testing of cations and anions are given in Table 3. Figures below 10% are not presented as in this paper, as alternative conceptions are considered significant only if they existed in at least 10% of a given sample (Tan et al., 2002).

Table 3
Alternative Conceptions of the Three Educational Levels of Students

Alternative conception	Choice combination	Percentage of students with the alternative conception		
		Sec 4	JC	G
Displacement				
1. A more reactive ion displaces a less reactive ion in an ion-exchange reaction.	Q1 (A3)	25	12	17
	Q5 (A1, A4)	37	35	27
	Q13 (A3, A4)	15	11	12
	Q18 (A1, A2, A4 & A5)	29	21	17
Redox				
A redox reaction occurs in an ion-exchange reaction.	Q13 (C1)	13	-	-

As with the cross-age study by Abraham et al. (1994), there were no predictable patterns in the frequency of alternative conceptions with respect to educational levels in this study, though in general, the percentage of trainee-teachers having alternative conceptions was the lowest, followed by junior college students and secondary students. Many alternative conceptions still existed despite exposure to increasing chemical education. The testing of anions and cations usually involves ion-exchange reactions resulting in the formation of precipitates. However, many of the participants at all levels believe that a displacement reaction takes place in which a more reactive ion displaces a less reactive ion (items 1, 5, 13 and 18). For example, when aqueous sodium hydroxide was added to aqueous zinc chloride, the participants believe that the 'more reactive' sodium ion displaces the 'less reactive' zinc ions (item 1, A3). The authors believe that the participants' learning/memorisation of the reactivity series of metals interfered with their understanding of ion-exchange reaction. This is illustrated by the following comments:

S52	:	Because…sodium hydroxide will displace the…zinc chloride…cos…the zinc chloride is less stable than sodium chloride…so…a displacement reaction will happen.
I	:	Why did you think of a displacement reaction?
S53	:	We've got the reactivity series…then we learn the displacement…so we apply.
I	:	Why did you think of the reactivity series…is there any reason?
S53	:	We were made to memorise the reactivity series…so it comes naturally.
S52	:	The teacher always stresses the importance of the reactivity series, so the moment you see sodium…you see metals like sodium…any metal from the reactivity series, even though it is an ion, you think of reactivity series right away.
I	:	Interviewer
S52 and S53	:	Secondary (Grade 10) students.

A small percentage of secondary students (item 13, A3, 13%) thought that a redox reaction was involved instead of an ion-exchange reaction because they mistakenly believed that there was loss/gain of oxygen when copper (II) sulphate (VI) reacted with aqueous ammonia. However less than 10% of the junior college students and trainee-teachers had this alternative conception. This indicated that the more advanced participants had a better understanding of redox models/reactions.

A further step in the test for cations is to add excess alkali to any precipitate formed to determine if the precipitate reacts with it to form a complex salt. For example, zinc hydroxide is amphoteric, and will react with excess aqueous sodium hydroxide to form the zincate salt, while copper(II) hydroxide will react with excess aqueous ammonia to form an ammine. However many secondary students, and to a lesser extent the junior college students and trainee-teachers, believed that the precipitate merely dissolved in the excess alkali because there was more space for it to dissolve, or no further reaction was seen and no new reagent was added. Knowledge of advanced inorganic chemistry could have helped the junior college and trainee-teachers here. The secondary students seemed to rely on perceptually-dominated thinking – if a solid disappeared in a liquid, then it dissolved in the liquid or if no new substance was formed then no reaction had taken place (Ebenezer & Erickson, 1996; Ribeiro, Pereira, & Maskill, 1990). This problem was further compounded by students being taught to write that the precipitate dissolved in excess reagent, a 'standard' answer required in the examinations to describe the disappearance of the precipitate. When several secondary students were asked why they used the term 'dissolve,' they either said that they were taught to do so or that it was given in the data sheet that they used for QA practical work. Thus, formal instruction could have caused students to have the idea in the first instance that dissolution took place, and perceptually-dominated thinking provided the explanation. Options A4 in item 2, a precipitate dissolved in a reagent because it formed a soluble compound with the reagent, was not considered as an alternative conception because the authors believed that though the term 'dissolve' was inappropriately used in this situation, the option could indicate that the participants understood what had occurred leading to the disappearance of the precipitate, and agreed with Brosnan

(1999) that understanding of the phenomenon in this case was more important than the terms used to categorise the phenomenon.

Many participants had difficulty understanding the tests for anions as shown by their responses for items 6, 11 and 17. For example, aqueous barium nitrate (V) and dilute nitric (V) acid are commonly used to test for sulphates (IV), sulphates (VI) and carbonates (item 11). The common alternative conceptions determined were that the reagents could only test for sulphate (VI), and that to test for a carbonate, acid had to be added directly to the unknown sample. Further examples were given in items 6 and 17 where the participants thought that dilute nitric (V) acid had to be added so that the unknown substances could react 'properly' with silver nitrate (V) and lead (II) nitrate (V), respectively. Many could not explain the function of the dilute acid as illustrated by the following comments:

I : OK…what about question 6?

S58 : I put acidify the mixture…basically I don't actually have a reason for it… basically because when we do practicals…we are told to acidify with nitric acid and they tell you that the purpose is to acidify…so I just take it at face value…that is to acidify the mixture and not for…I don't know like why you need to acidify it

I : Have you wondered why you need to acidify?

S58 : No because I accept things…the way they are…as in if you tell me I have to acidify if it is part of the procedure I need to do it during practicals then I will just do it because I know I'm supposed to do it… and also because we are not questioned why either…so there is no desire to find out why since you are not questioned why

I : What's the purpose of the acid

TT4 : Acidify.

I : OK…reason?

TT4 : I choose number 4 because there is no other choice which…I think…because like what I said…I never know…why…because we were not told…so I think …acidification is necessary so that reaction can be carried out properly.

I : What do you mean by reaction can be carried out properly?

TT4 : May be we need hydrogen ions…in order for the mechanism to work…for the reaction mechanism to work.

TT : trainee-teacher

The secondary student and trainee-teacher did not realize that the function of the acid was to react with sulphate (IV) or carbonate ions, if present, producing sulphur dioxide and carbon dioxide which could be identified by the appropriate tests.

In summary, many of the participants had alternative conceptions, even the more advanced chemistry participants, and this indicated that the alternative conceptions were "robust enough to have survived schooling" (Palmer, 1999, p. 648). When interviewed, many secondary students admitted that they had little idea about what they were doing during QA practical sessions (Tan et al., 2001). They often did not know why they were instructed to use a certain reagent, what they were testing for, what reactions occurred, or why they obtained a particular result. The authors believed that the main reason for the participants' lack of understanding of QA was the requirements of QA practical examinations – presently, students were assessed only on their written reports and the bulk of the marks were allocated to correct observations and identification of the unknown substances. Thus, students could do very well just by writing all the correct observations and making required inferences with the help of the data sheet. This lack of emphasis on understanding led to a situation where teachers tended to concentrate more on 'drill and practice,' doing past years' examination questions and writing 'model' answers than on enhancing students' thinking and understanding. The following comment of a teacher highlighted the focus of her QA lessons:

> I only gear them towards observations because the O-levels only require them to write the correct observations…so I gear them towards recording the correct observations, how to carry out the tests, how to get marks from the report…so I'm very focussed…I don't have time to explain every detail…what *reaction is taking place.*

Two trainee-teachers commented that they also focused on results, even when they did QA practical work in the university, rather than on the understanding of the procedures and reactions involved.

TT4 : Personally for me…from day one when I did QA till…in the university right…it's all about results…you were never asked why…so it's like you have to produce results…it's like you're given a list…so if you check and find that this…result corresponds to this compound…and …you never stop to ask yourself why because you don't have the time…you really have to do it…and the lecturers never ask you why…you just concentrate on getting the results.

TT3 : Yah…same here…the teachers never emphasize why.

TT4 : You just concentrate on the results.

I : So you feel this affects the learning of QA.

TT4 : It affects…because you just blindly follow the list and you know that oh…I get yellow so I go to the QA list and see which one is yellow but I don't really know what is happening.

Thus, the nature of examinations has significant impact on implemented curriculum (Hodson, 1993), and students and teachers tend to focus mainly on the aspects of QA that will bring in the marks. To encourage more meaningful learning of QA, the present system of assessment needs to be expanded to include the assessment of manipulative and planning skills, as well as the understanding of the concepts involved in QA. Indeed, these are the focus of the new practical assessment system which will be implemented in Singapore in the near future. Making these changes could lessen the need for 'drill and practice,' and encourage teachers to provide the appropriate experiences for the meaningful learning of qualitative analysis.

CONCLUSIONS

This cross-age study showed that, in general, many participants did not have adequate understanding of basic secondary QA. Though the trainee-teachers (mean score 51%) performed significantly better than the junior college (43%) and secondary students (30%), their scores were still low – 50% of them scored 51% and below in the QADI. The prevalence of alternative conceptions among the advanced chemistry participants showed that there were common conceptions among all the participants, and that the alternative conceptions were retained even with additional years of chemical education (Abraham et al., 1994; Birk & Kurtz, 1999; Palmer, 1999; Watson, Prieto, & Dillon, 1997). Many of the advanced chemistry participants still had little understanding of the procedures and reactions involved in qualitative analysis, or were unable to apply their additional knowledge. Thus, there needs to be a rethink in the way QA is taught and assessed.

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APPENDIX: EXAMPLES OF ITEMS IN THE QADI

For Questions 1 and 2, refer to Experiment A:

Experiment A

Step	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	A white solid is obtained.
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	White solid disappears in excess reagent to give a colourless solution.
c	Add dilute nitric (V) acid (HNO_3) to the mixture from (b) until no further change is seen.	White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.

1. What happens when aqueous sodium hydroxide is added to aqueous zinc chloride resulting in the white solid?

   A Displacement

   B Precipitation

   C Redox

   Reason/Justification

   (1) The solution is too concentrated with sodium chloride so the sodium chloride comes out of the solution as a solid.

   (2) Sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide.

   (3) Sodium ion is more reactive than zinc ion.

   (4) Zinc ions combine with the hydroxide ions.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

   A. dissolves in B. reacts with

   Reason/Justification

   (1) More solvent is added so there is more space for the white solid to dissolve.

   (2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.

   (3) Sodium ion displaces the cation from the white solid.

   (4) The white solid forms a new soluble compound with the excess sodium hydroxide.

3. A student is given a solution which may contain carbonate ions. She decides to add aqueous barium nitrate (V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric (V) acid. Is it possible for her to determine whether carbonate ions are present when she carries out the above procedures followed by the identification of the gas involved (if any)?

   A. Yes B. No

   Reason/Justification

   (1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid.

   (2) Dilute nitric (V) acid will react with both a soluble and an insoluble carbonate.

   (3) The above procedure is strictly to test for the presence of sulphate (VI) (SO_4^{2-}) only.

   (4) The acid must be added directly to the solution to test for the presence of a carbonate.

   (5) The unknown compound will only react with the dilute nitric (V) acid and not with the barium nitrate (V).