The topic, qualitative analysis, is an important component of the G.C.E. 'O' level chemistry course in Singapore. Students are required to carry out a series of procedures using chemicals, apparatus and appropriate techniques. They then have to observe and record what happens, and make inferences based on their observations.

Many teachers find that upper secondary chemistry students do not understand what they are doing in the qualitative analysis laboratory sessions. Teachers frequently complain that students adopt a recipe approach, do not understand the purpose of the experiments, and frequently do not think for themselves. Students often resort to asking their teachers for help in recording and making sense of their observations, and seldom bother to understand what is going on in the experiments. Qualitative analysis appears not to be meaningful to the students; it is some thing that they have to do to pass the examinations. Getting the correct results and knowing how to write "standard" answers will lead to good marks, and that is all that matters.

Why do students have problems in carrying out the experiments in qualitative analysis, and making sense of their results? What is it about qualitative analysis that makes it so difficult to master and puts many students off?

Tasker and Freyberg (1985) wrote:

Our observations have shown that pupils did not have any idea of what were the critical scientific factors in the experiment, even though teachers assumed that they did. Pupils had little appreciation for features in the design of an investigation and consequently no real basis for anticipating the nature of its outcome. (p. 71)

Forty one Secondary Four (15 to 17 years old) students from three secondary schools in Singapore were asked, in interviews, the aspects of qualitative analysis that they found difficult, and the reasons why. Some of their comments are given below.

S6: You have so many gases and then there is a different test for each gas, so if you do the wrong test, you have to repeat it ... you just keep doing it until you find out.

S8: Sometimes we don’t know how to test for all the gases at one time when there are so many gases, and sometimes we can’t guess what kind of gases may be evolved.

S9: I mean it’s like you’re learning blindly … you don’t know whether it’s going to be a hydrogen gas test or a 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 will be directing hydrogen gas into limewater instead and it doesn’t do anything. But by then you can’t put the lighted splint and let it extinguish. You really don’t know what is coming out.

S18: At first, right…we were just told to mix this and this … and then without knowing what was inside it. I really did it blindly so I didn’t know anyway … in fact I didn’t know what was inside … what chemical … or what.
If you are not familiar with the reagent used, you don’t know what it is for ... you will have difficulty.

I think the main thing is that we don’t know what we are testing for. So when you don’t know what you are testing for, you cannot come to sort of a conclusion.

It’s like if they give you a question asking you to...add in a reagent like...sodium hydroxide ... I’m... I won’t be sure like... what cation or anion they are trying to test.

I think she means like we won’t know what we are testing for ... we always do this thing blindly and then at the end when we have to make some ... deduction ... then we just guess...or just flip, flip, flip, flip through our QA book ... yah.

So if it happens that you did not do the test properly and the result is not what you are supposed to obtain, you wouldn’t know it. Whereas if you knew what you are testing for, you will expect a certain result. So if you get something that is different from the result, you know that you did it wrongly... but usually we don’t know that.

Sometimes it’s like...we’re suppose...we have this portion of this unknown substance ... we don’t know whether we should use a little bit or a lot in order to get the results that we want and we need ... so I don’t know ... it’s like we’re lost in the whole experiment and we don’t know what’s happening ... yah.

We’ve been taught just to memorise if you do this, this happens, but we don’t know the reason or why. We come to the lab ... we do all the experiments, everything...but we don’t know why we’re doing it, so we’re doing the practical but we’re sort of like ignorant of the theory.

When you have your results, when you obtain your results, it might defer from the person next to you, you see. So maybe you get panicked also, so you try to redo, that means you are not giving yourself confidence ... yah, something like that.

We’re just given this, you see...and the tables like...given the tables and you follow...you add sodium hydroxide you get this result it signifies this, you add ammonia you get this, you see. So that’s what we learn...we don’t...it’s no why this is added and how it affects...we don’t learn that.

I also do not understand...actually we have never ... we never thought of that before ... why is there a precipitate.

I think maybe in the beginning, it would be better if the teacher explains more and tells us why this happens and gives us the theory and saying...like...and refer to previous lessons like...remember last week we did this and this is what happens, and if you do this in the practical now, you can understand better.

The above comments confirm the observations of Tasker and Freyberg (1985). Teachers will also agree with Tasker and Freyberg. Very often when teachers ask students to explain what they are doing or why they are adding a certain reagent, they receive answers such as "don’t know" or "I’m just following what is given in the worksheet”. If the critical features of the experiment are not appreciated, then the student’s aim becomes “one of guessing what the teacher wants from an activity or ‘getting the right answer’” (Tasker & Freyberg, 1985, p. 74). Thus qualitative analysis is reduced to a mechanical level which has little intellectual involvement.
Many students think that qualitative analysis mainly involves memory work, that is, they just need to memorise what happens when different reagents are added to different ions; they think that qualitative analysis is merely the matching of the results that they obtained with their memorised knowledge of reactions to reach certain conclusions. This is evident in the exchange below.

I: How do you find qualitative analysis?
S32: Need a lot of memory because you have to memorise a lot of things, the colour, the formulas ... know what is being produced and so on.
S33: Must find conclusions also ... kind of difficult sometimes ... because you like he says need a lot of memory ... have to memorise what colours all these ... sometimes we forgot about the colours then cannot come to conclusion ... what does this contain.

How can qualitative analysis be made more meaningful to students? How can students be encouraged to think critically in qualitative analysis experiments?

In addition to the manipulative aspects of the experiments, students need to learn to think the experiment through. This is something that they do not do with their normal recipe approach to qualitative analysis. The thinking process should starts with the reading of the procedures given in the question. Questions such as "What is this procedure for?", "What reactions are involved?", "What products can I get?", "Do I need to test for a gas, and if so, what tests do I need to prepare?" should be racing in the minds of the students. When they obtain results, they have to ask themselves, "Do I expect to get such results?" and "Does it agree with what I thought I would get?". When students get unexpected results, many would just redo the experiment or ask their classmates for the "right answer" without analysing what went wrong and why they obtain the "wrong" answers. This results in valuable learning experiences going to waste.

Students will eventually appreciate the advantages of understanding what they are doing in the experiments, as explained, below, by a student.

S9: So when you understand it, it’s like you realise, you’ll be like...thinking you see. If something goes wrong, you know that it’s wrong, you see...rather than you’re following one straight line, because of what you studied blindly before, and if you are...the first step is wrong, everything will be wrong, you see. It is better if you understand the...what you...you’re studying and then when you apply it, you...if you make a mistake, you can understand why. You can question your results also you see...why is this result like that and then maybe you can go back a few steps.

The first step in the critical thinking process is to decide what the aim of a given procedure is. The information on the above is given by the reagents to be used in the procedure. For example if aqueous sodium hydroxide is to be added to an unknown sample, the use of sodium hydroxide will most likely be for the determination of the cation in the unknown sample. The next step is to determine what reactions will be involved and what products will be obtained. In the case of aqueous sodium hydroxide, a double decomposition reaction may occur, resulting in the formation of an insoluble hydroxide. Whether a precipitate is formed, and if it is, the colour of the precipitate and whether it is "soluble" in excess sodium hydroxide will give clues to the identity of the cation. Students should also realise that an amphoteric hydroxide-sodium hydroxide reaction, leading to the formation of a soluble complex salt is responsible for the precipitate "dissolving" in excess sodium hydroxide. Thus by understanding the reactions that occur when a procedure is carried out, one can predict the possible results that one can obtain. Knowing the reasons why the results are obtained is more meaningful than merely referring to the qualitative analysis handbook or data sheet, and
trying to match the results with what is given in the handbook or data sheet in order identify
the unknown ions. Very little learning occurs when students simply refer to the handbook or
data sheets to get answers as many will not understand what is going on and what they are
doing in the experiments. Another advantage of understanding the reactions involved is that
students also link and apply what they have studied in other topics such as "Acids, Bases and
Salts", "Reactivity of Metals", "Reduction and Oxidation" with qualitative analysis to get a
more complete picture of the chemistry that they are learning.

Many students find qualitative analysis tedious and boring because they do qualitative
analysis experiments week after week without understanding what they are doing. They need
to be given time to think about what they do, rather than merely doing experiments every
laboratory session. Teachers should check their students' understanding of the reasons behind
the procedures early in the course. After familiarising themselves with the various tests for
cations, anions and gases, students could be asked to suggest tests for a specified compound
and their reasons for choosing the tests. For example, a teacher could ask the students what
tests they would carry out to confirm that a solution contains zinc and chloride ions. Students
will find it easy to state the use of aqueous sodium hydroxide to test for zinc ions and aqueous
silver nitrate followed by dilute nitric acid to test for chloride ions. However, if they are
asked to explain why the above reagents are used and what reactions occur, most will be
tongue-tied: they will not be able to explain the important concepts and reactions in
qualitative analysis.

The next step in teaching students to think critically in qualitative analysis is to make them
analyse the worksheets. Students should be able to determine, from the procedures given,
what the procedures are for, what reactions will occur, what results they could expect and
whether there is a need to prepare to test for gases which might be liberated if they carry out
the procedures. Students do not have to carry out experiments in every laboratory sessions,
they could occasionally do the experiments "mentally" and learn a great deal from these
mental exercises. Students could practise analysing the qualitative analysis worksheets in
pairs to determine what the procedures are for, what reactions are involved, what results to
expect and what test for gases to prepare for, if any. They can then present their analyses to
the whole class and their peers can evaluate their analyses and give them feedback. In this
way, students are actively thinking, instead of being mentally passive and physically active as
in normal laboratory sessions.

This critical thinking process can be carried a step further when students are actually doing
the experiments. Students could be asked to work in pairs and to think aloud while carry out
the procedure given in the worksheets. They could voice their thoughts on their
understanding of theory behind the procedures such as what reactions are involved, what
results to expect, what tests to prepare to test for gases if any, and whether their hypotheses
agree with the results obtained. They could even comment on their experimental techniques,
such as, how much reagent to add, what apparatus to use, how to heat, how to test for gases
and how to determine the correct colour of a precipitate in a coloured mixture.

Many teachers find that upper secondary chemistry students do not understand what they are
doing in the qualitative analysis laboratory sessions, do not think for themselves and adopt a
recipe approach in the laboratory sessions. From the interviews with the students, it can be
seen that they do not understand the critical features of the experiments and this creates
problems for them. Thus teachers should not concentrate merely on the "doing" and "correct
answer" aspects of qualitative analysis, neglecting the "thinking" in the experiments.
Meaningful learning requires active thinking. The way to make qualitative analysis more
interesting and relevant to students is to encourage them to think critically on what they are
doing during the experiments and to make explicit links with the theory learnt. Teachers may
complain that they do not have time for such thinking activities as students need practice doing experiments to prepare for the practical examinations. However, they need to consider whether it is better for students to do more worksheets in a cookbook fashion, or for students to do less, but with more thinking and greater understanding.

Reference