Secondary Students' Perceptions about Learning Qualitative Analysis in Inorganic Chemistry

Authors:

Kim-Chwee Daniel, Tan

Ngoh-Khang, Goh

Lian-Sai, Chia

National Institute of Education, Nanyang Technological University

(Until mid-November 2000)

469, Bukit Timah Road

Singapore 259756

(From mid-November 2000)

1 Nanyang Walk

Singapore 637616

David F. Treagust

National Key Centre for School Science and Mathematics

Curtin University of Technology

GPO Box U1987

Perth, Western Australia 6845

Secondary Students' Perceptions about Learning Qualitative Analysis in Inorganic Chemistry

Abstract

Grade 10 students in Singapore find qualitative analysis one of the more difficult topics in their external examinations. Fifty-one Grade 10 students (15 to 17 years old) from three schools were interviewed to investigate their perceptions about learning qualitative analysis and the aspects of qualitative analysis that they found difficult. The results showed that students found qualitative analysis tedious, difficult to understand and found the practical sessions unrelated to what they learned in class. They also believed that learning qualitative analysis required a great amount of memory work. It is proposed that their difficulties may arise from not knowing explicitly what is required in qualitative analysis, the content of qualitative analysis, the lack of motivation to understand qualitative analysis, cognitive overloading, and the lack of mastery of the required process skills.

Secondary Students' Perceptions about Learning Qualitative Analysis in Inorganic Chemistry

Introduction

Secondary students (13 to 16 years old) in Singapore sit for a national examination, the General Certificate of Education Ordinary Level (O-level) Examinations, when they are, on the average, 16 years old. Chemistry is one of the subjects that students can take in the O-level examinations and the chemistry examination consists of one practical and two theory papers. Qualitative analysis (QA), which involves the testing for oxidising and reducing agents, and the identification of anions, cations and gases as specified in the syllabus (University of Cambridge Local Examinations Syndicate, 1996), is a topic that is often assessed in the practical paper. Many of the students who were interviewed found QA difficult. This paper seeks to highlight students' perceptions about learning QA, the aspects of QA that they found difficult, and the possible reasons for the difficulties.

Zubrick (1992) and Zieger (1993) believe that traditional 'wet chemistry' qualitative analysis is still relevant in the age of powerful modern computer-controlled analytical instruments because students learn process skills as well as carry out many of the reactions that they learn in their lessons and textbooks. Practical sessions are ideal for bringing the macroscopic, microscopic and representational aspects of chemistry together (Johnstone, 1999). Thus qualitative analysis is very relevant and important to a chemistry course as it strengthens the students' understanding of chemistry (Cooley & Williams, 1999).

However, qualitative analysis is a difficult topic for students to learn as it involves both process skills as well as the understanding of many chemistry concepts (Goh, Toh, & Chia, 1987; Tsoi, 1994). Goh et al. (1987) studied the questions on how students can be adequately equipped with essential science process skills in qualitative analysis, and how these process skills can be correctly assessed during science practical work. They developed a schema, the Modified Laboratory Instruction (MLI), for improving the mastery of process skills, and found that students who had experienced the MLI schema generally did better in a practical test and a pencil-and-paper alternative-to-practical-test than those who were taught using traditional methods. These students also showed more positive attitude toward laboratory work, as well as greater confidence in their own manipulation of laboratory apparatus. Similar results were obtained by Tsoi (1994) who extended the study of MLI to include computer-assisted instruction. Apart from the abovementioned works, no other significant study on students' difficulties and perceptions about their learning of qualitative analysis could be found in the literature.

Methodology

Fifty-one Grade 10 students from three secondary schools were interviewed to ascertain their perceptions about learning QA, the difficulties that they encountered, whether they perceived any links between theory and practical work, and their understanding of the procedures and reactions involved in the practical work. These 51 students were either chosen by their teachers (Schools R and S) or had volunteered to be interviewed (School M). Students in Singapore are generally uncomfortable being interviewed by strangers, so the students were interviewed in pairs or threes to put them at greater ease. Table I describes the composition of the various groups interviewed and the schools from which they came. Each interview lasted between 45 minutes to an hour, and examples of the questions asked are given in Figure 1. According to Duit, Treagust and Mansfield (1996), the social dynamics of such interviews might skew discussions, so a conscious effort was made to give equal opportunity to all the interviewees to have their individual say. One of the main benefits of pair or group interviews is that students are able to talk to each other, to develop, challenge and clarify ideas (Duit et al., 1996; Gilbert & Pope, 1986). This was important as it was found that the students previously had not given much thought to the procedures and reactions in QA; consequently, they were forced to start formulating and organising their thoughts during the interviews to answer the questions posed to them, and peer discussions helped in the process.

TABLE I about here

Figure 1 about here

Results and discussion

In general, many of the students interviewed did not like QA practical work, had little idea what they were doing during practical work, were concerned with getting the correct results and feared getting results which did not tally or were different from their classmates. They also believed that QA involves mainly memory work. The findings on students' perception of QA and the difficulties that they encounter are summarised in Table II, and discussed under the following headings, 'Tedious and irritating', 'Knowing what to do or what we are doing', 'Results – right or wrong', and 'Memory work'.

TABLE II about here

Tedious and irritating

Twelve of the students interviewed did not like QA practical work as typified by an excerpt of the verbatim transcript from Student 1 who stated that "We do QA almost every practical…quite, shall we say irritating because you always have to do the same thing again and sometimes you get frustrated because your results don't tally and you can't find an answer. So it gets frustrating some times."

Teachers normally begin teaching QA by reviewing the reactions involved and demonstrating some procedures that the students need to carry out. Students then do a series of tests for the various cations, anions, gases, oxidising and reducing agents as specified in the syllabus (UCLES, 1996). After they are familiar with the tests, students are given past years' examination questions to determine the unknown ions present in the given samples. Thus, students will do QA practical work continuously for about 10 to 15 weeks. This might be why Student 1 found QA irritating. Other students found QA practical work tedious, for example, Student 14 explained that there were many procedures to carry out in QA practical work, especially when testing for gases, and Student 12 stressed the need to be meticulous, for if the results did not tally, one had to redo the whole experiment and it was very tiring to do so.

Knowing what to do or what we are doing

In their study of practical work in school, 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)

Twenty-six students admitted that they frequently did not have any idea about what they were doing during the QA practical sessions. Fourteen students mentioned that when they had to test for a gas, they did not know which gases to test for in a given situation, hence, they randomly tested for all the gases that were in the syllabus. This resulted in them wasting time testing for the 'wrong' gases, and using up all the gas evolved before they could complete all the tests. Pintrich, Marx and Boyle (1993) stated that the student's belief that he/she could accomplish a task motivated him/her to be cognitively involved in the task. Unfortunately, many students who were interviewed seemed to be clueless about what to do during practical work, as typified by Student 6's response to being asked what aspect of QA she found difficult – "Testing for gases because you have so many gases and then there's so…different tests for each gas…so if you do the wrong test for that…gas…then you have to keep on trying until you can determine what gas it is." Many students did not realise that the procedures and the reagents used could indicate which gases might be evolved during the process. Hence, they randomly tested for the gases specified in the syllabus. The lack of understanding of the reagents used in QA practical work and the reactions that occur is further shown by the comments of 19 students that they often had no idea why they were instructed to use a certain reagent or what they were testing for, and that they did not know what were the reactions which occurred or why they obtained a particular result. Excerpts of the students' laments are given below.

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 QA book.

Another consequence of students not knowing what procedures are for was that they had problems making inferences from their results, as typified by Student 30's complaint, "I just cannot deduce the final product…what is the ion present…the thing is I don't know what will happen if I add this kind of reagent". The students had already learned the reactions involved in QA in the chapters 'Acids, Bases and Salts', 'Redox', 'Reactivity of Metals' and 'Periodicity', but it seemed that they were unable to link what they were doing in the QA practical work with the theory that they were taught in the classroom.

"Procedural understanding, ideas about acceptable laboratory practice, perceptions about the purpose of the investigative task, and the physical and temporal constraints of their situation will influence the investigative behaviour of any group of students" (Campbell et al., 2000)

Sweeney, Bula and Cornett (2001) reported that in a practical work session where students had to identify a series of unknown compounds, the students "preferred to follow prescribed, step-by-step instructions, and struggled even then to understand the chemical concepts which provided a rationale explaining why these steps were being followed" (p. 418). Students "found it difficult to transfer their declarative knowledge of chemistry into the procedural knowledge required to complete the laboratory investigations successfully' (p. 418).

Results obtained – right or wrong

Many students feared getting unexpected results or results which differed from those of their classmates, and getting results for different parts of the experiment which do not tally with each other. A comment from Student 2:

S2 : OK, let's say you are supposed to add hydrochloric acid to the unknown. You expect it to be a carbonate…but somehow the results …they come out to be different…then you can't decide whether you should write down what you think it should be or whether you should write down your actual results.

Student 2 was unable to evaluate an unexpected result in her experiment so she did not know whether to ignore the result and write down what she thought it should be, or to describe it as it was.

Student 33 also had similar experiences during experiments.

S33: When others get results which differ from mine…I wonder why our results are so…different.

I : What do you mean by different results? Can you give an example?

S33: For example…their white precipitate is soluble in excess…but mine is not…it's stressful.

The students did not have confidence in the results that they obtained especially if the results were not what they anticipated or if the results differed from those obtained by their classmates. They avoided risk taking and were reluctant to “venture forth with ideas or statements that might be considered bizarre or far-out” (Costa, 1991, p. 104). These students often believed that the results that they obtained were incorrect and rejected them on the grounds that their samples or the reagents used were contaminated, or that they did not follow instructions properly. The following excerpt illustrates this:

S24: …sometimes when you add two chemicals together…you…you may not get the results you want.

I : What do you mean?

S24: For example, in the lab…you might add two chemicals, you are supposed to see a precipitate…you don’t see it…maybe because of some contamination or something like that.

The secondary students’ responses to ‘anomalous’ results also were commented upon by the examiners for the O-level chemistry examinations. The examiners believed that students had first decided on or guessed the identity of the unknown ions before carrying out the procedures. If the actual results proved otherwise, the students would reject those results and wrote what they believed should happen. The following are excerpts from various examiners’ reports on the practical examinations:

> Most correctly reported a white precipitate although disappointingly a significant proportion failed to spot that it dissolved when nitric acid was added. Whether this was due to bad practical technique or to candidates deciding that R was a chloride and therefore the precipitate should not

> dissolve is hard to say. Candidates should be encouraged to carry out the test first and then attempt the inferences rather than trying to work out practical observations having guessed, often wrongly, the identity of the unknown substance. (UCLES, 1994, p. 32)

> Several tests required the observation ‘no reaction’ or ‘no change’. This lack of reaction worried several candidates who promptly invented observations…. With S, the addition of aqueous barium nitrate does not produce a precipitate, but the addition of acid leads to the slow formation of a white precipitate which then becomes yellower. Many reported a precipitate on the addition of the aqueous barium nitrate, presumably because they had decided that the solution contained a sulphate or sulphite. (UCLES, 1997, p. 30)

Memory work

Sixteen students expressed the opinion that QA involved a lot of memory work, as illustrated by the following excerpt:

S30: I…don’t really like QA.

I : Why don’t you like QA?

S30: It’s just that…I don’t like memorising.

I : What do you mean by memorising?

S30: You need to memorise what happens when you add a reagent to a certain ion, for example, the colour of the precipitate.

Fourteen students believed that qualitative analysis mainly involved memory work, that is, they just needed to memorise what happened when different reagents were added to different ions (Tan, Goh & Chia, 1999). It appeared that either rote learning was the preferred mode of learning of many students or they treated the memorisation of data as a 'security blanket'. Once they had memorised the knowledge, they felt confident that they could deduce the identity of the unknown ions from their results to get the correct answer. They seemed to believe, as Carr et al. (1994) pointed out, that those who were able to memorise enormous quantity of facts would do well in science, or in qualitative analysis in this instance, and those who did not have such ability will not perform as well as those who had. Reif and Larkin (1991) also stated that students primarily strive to memorise information because they believed that science was merely a collection of knowledge. However, one of the shortcomings of merely being able to recall facts was that students were not able to evaluate 'anomalous' results to determine if the results were possible or if they had made experimental errors. They needed to understand the procedures and reactions, and to think critically in order to evaluate their results.

In summary, many of the students who were interviewed found QA practical work tedious and uninteresting, they had little idea about what they were doing in the practical sessions and could not link theory and practice. Thus, these students were not confident in carrying out the procedures and were often unsure of the results they obtained. This resulted in the frequent checking of results with classmates and teachers, and at times, ignoring actual results obtained in favour of the results that they thought they should have obtained. They also felt that memorisation of facts was important in QA. Freedman (1997) believes that laboratory work has a positive influence on students' attitude toward science and their achievement because it makes science interesting and encourages students; however, this is most likely not the case for QA practical work in Singapore schools. To paraphrase the words of Hodson (1990), to many of the students interviewed, QA practical work seems to contribute little to the learning of chemistry or learning about chemistry, nor does it engage the students in doing chemistry in any meaningful sense.

Reasons why QA is difficult

The authors believe that the students' difficulties in QA arise mainly because of their lack of understanding of the procedures and reactions involved in QA. One reason for this situation could be that the requirements of QA were not made explicit to the students. The content (White, 1994) of QA is rather extensive as it involves propositional and procedural knowledge, as well as manipulative and inferential skills, and this could also pose a problem to the students, resulting in students experiencing cognitive overload (Johnstone, 1984;1999; Johnstone & Wham, 1982) during the QA practical work and carrying out the procedures in a haphazard manner. Students also do not have the incentive to understand the procedures and reactions involved in QA as it is not required for them to do well in the practical examinations – writing the expected observations is sufficient. The reasons proposed for the students' difficulties are further elaborated in the following sections.

Not knowing what is required

Many of the students who were interviewed said that they did not understand what they were doing in the QA laboratory sessions, and could not see the links between what they had learnt in class and what they did in practical work. This lack of understanding was also highlighted by the O-level chemistry examiners in various reports (UCLES, 1994; 1995; 1997; 1998). The problems most probably arise because the students may not know what to think about in QA and what to take note of in the first place. However, teachers assume that they do, and thus, seldom emphasise or make explicit the purpose of, and the theory behind the procedures (Tasker & Freyberg, 1985). Fensham and Kass (1988) also believed that the inconsistency "between the teachers' intentions and their students' attentions" (p. 10) in practical work is very common. These discrepancies in intent would lead to discrepancies in action (Tasker & Freyberg, 1985); students' actions are governed by the purpose they establish for an activity, so if the tasks in the QA practical work are not clearly defined by teachers, students must define the tasks for themselves and provide their own goals and structure (Pintrich et al., 1993). Unfortunately, left to themselves, students have "difficulty establishing any meaningful overall purpose [in the experiments, so] their purpose and actions degenerate to simply following instructions" (Tasker & Freyberg, 1985, p. 72), and the tasks of assembling apparatus and making required observations or measurements become the focus of student action (Gunstone, 1991). QA is, therefore, reduced to a mechanical level which has little intellectual involvement. This contrasts with the teacher's expectation that students understand the procedures that they carry out and the results that they obtain.

Another consequence of the lack of direction in experiments is that 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). The 'right' answer becomes the goal, undermining the importance of the processes leading to the answer and leading to little cognitive involvement (Pintrich et al., 1993). Unfortunately, teachers place great importance to getting the 'right' answer, and the erroneous aim of the practical work is reinforced.

One more example of students not knowing what is required in practical work is that they often do not know what to observe in QA and what valid inferences to make from their observations; when the first-named author taught QA, he had frequent requests by students for help in writing observations and making sense of the observations. Gunstone (1991) believes that students do not understand issues such as the nature of observations, the purpose of a particular observation, what a valid observation is, what valid inferences may be made from observations, and the differences between observations and inferences. He argues that this lack of understanding arises because these issues are not explicitly addressed in science teaching.

The lack of theoretical understanding underlying practical work could also be a cause for students not knowing what they are doing during practical work (Hodson, 1993). McDermott (1988) contends that one of the causes of students' lack of understanding of chemistry is the failure to integrate knowledge. This is seen in QA where students either cannot, or, do not know that they have to make extensive links between theory and practical work. The comment by Tasker and Freyberg (1985) that lessons are frequently seen by students as isolated events with no connections to the previous lessons or topics also rings true in QA. Again, this is most likely due to the lack of appropriate frameworks that could guide their investigations (Duit & Treagust, 1995; Gunstone, 1991), something which teachers may have neglected to develop in their students.

Content of QA

Another reason why students find QA difficult could be the content of QA. White (1994) describes several properties of science content that influence how the content should be taught and learned. These are openness to common experience, abstraction, complexity, presence of alternative models with explanatory power, presence of common words, mix of types of knowledge, demonstrable versus arbitrary, social acceptance, extent of links and emotive power. Students do not encounter QA in normal everyday life, so they have virtually no conception of it until they encounter it in school. The concepts behind the procedures in QA and the reactions that occur are abstract, complex and extensively linked. For example, Fensham (1994) pointed out that students found what happened when substances were heated confusing because the substance might dehydrate, decompose, change its state, or undergo a combination of the processes! QA also involves a mix of knowledge and skills, such as propositional and procedural knowledge, and manipulative and inferential skills. Thus, it is not surprising that students find QA very demanding and difficult.

Cognitive overloading

Nakhleh and Krajcik (1994) contend that “a laboratory experiment is a complex learning environment, and students may become so overwhelmed with the task at hand that they literally have no memory space left with which to think conceptually” (p. 1095). This is in agreement with Johnstone and Wham (1982) who suggest that there is too much ‘noise’ in practical work in general. Johnstone and Wham argue that the working memory of students is bombarded with information of various kinds, such as, written and verbal instructions, new manipulative skills, unfamiliar labelling of reagents, and inputs from the experiment itself. In addition, students have to recall manipulative skills and background theory, and associate names for apparatus and reagents. Thus, practical sessions seem to consist of “an avalanche of things to do and little time is left for thought” (Johnstone, 1999, p. 46). This is definitely true for QA as students need to read instructions, select reagents, carry out procedures, prepare additional tests, observe, record and interpret their results, as well as being mindful of the time left to complete the experiments and their reports. The resulting overloading of the working memory leaves "no space for thought and organisation and so faulty (or even no) learning takes place" (Johnstone, 1984, p. 847).

Lack of mastery of required skills

A common complaint of teachers is that students do not know how to carry out the procedures in QA experiments properly. However, Goh et al. (1987) commented that the mastery of science process skills of secondary students was usually left to chance because many teachers did not spend time in helping students develop such skills. Consistent with this comment, Herron (1996) stated that:

> We seldom make deliberate efforts to teach laboratory skills that, much to our chagrin, students have never learned. By teaching, I do not mean telling students what to do or performing a quick demonstration in front of the class. I mean carefully prepared lessons, with clear statements of expectation, feedback to individual students so that they can correct errors, and evaluation at the end of instruction to be sure that the lesson is learned. I am talking about doing what any good coach would do in teaching a psychomotor skill. (p. 20)

Similarly, Hodson (1990, p. 36) succinctly summed up the situation by stating that "It is not that practical work is necessary in order to provide children with certain laboratory skills. Rather, it is that certain skills are necessary if children are to engage successfully in practical work."

In QA, teachers need to explicitly teach students skills such as how to dissolve substances, add reagents to the unknown samples, test for gases, and heat substances. They also need to ensure that their students practise and master these skills. Unfortunately, many teachers do not. It comes as no surprise that Goh et al. (1987) found that many students lack mastery of process skills in QA.

Motivation to understand

Goh et al. (1987) highlighted that ‘drill and practice’ in QA practical work has become pervasive in schools to prepare students for the practical examinations. This is because getting good results in the practical examinations 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. This ‘drill and practice’ practical work demands little cognitive effort but pays off handsomely in terms of results. This “backwash effect of examinations” (Skemp, 1974, p. 24) works against the aim of understanding what one learns – especially if understanding is not essential for doing well in the practical paper! Since there is no apparent incentive for students to spend time and effort understanding what they do in QA, they tend to follow instructions without much thought and thus, little useful learning occurs (White, 1991).

In addition, this performance goal of getting the ‘right’ answer may be embraced and reinforced by the teachers and school administrators themselves. Teachers may concentrate more on doing past years’ examination questions and writing ‘model’ answers than on enhancing students’ thinking and understanding. This aspect is illustrated by the following comments of a teacher:

> 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.

School administrators, mindful of the school's position in the school performance league table in Singapore, most likely encourage and reward teaching and learning activities which enhance examination results. Consequently, the goal orientation beliefs (Pintrich et al., 1999) of the students, teachers and schools work against the mastery learning of QA. Rop (1999) describes the situation aptly by stating that "there are significant sociocultural incentives and pressures that support traditional school performances than for deep understandings of chemistry" (p. 222).

Conclusion

Hidi (1990) believes that interest is important to "cognitive functioning and the facilitation of learning" (p. 565). Thus, it is possible that those who find QA 'tedious' and 'irritating' would be less motivated to cognitively involved in QA, resulting in it being even less interesting and more mechanical. Marzano and Pickering (1991) stress the need to establish an appropriate "attitudinal environment" (p. 94) and that teachers need to structure the learning tasks for success, make the tasks valuable and relevant to the students, and communicate to students a sense of confidence in their ability.

Students' lack of confidence in their experimental results and students attributing unexpected results to experimental errors also have been reported in the literature. In their study on the response of science students to anomalous data, Chinn and Brewer (1993) suggest that one of the reasons that individuals give to reject anomalous data is that "the procedure by which the data were collected is flawed" (p. 6). Gunstone (1991) also found that science graduates in a pre-service teaching programme rejected observations which did not meet their expectations “via a denial of the legitimacy of the observations” (p. 72), and Duit and Treagust (1995) reported that “empirical studies in the field of psychology indicate that humans in general tend to observe only what fits their conceptions and to ignore counterexamples” (p. 50). The authors believe that the lack of relational understanding (Skemp, 1976) of the procedures and reactions, the critical factors of the experiment, could be the main cause of student difficulties in QA. If students know why they are carrying out a given procedure and what reactions are likely to occur when they use a given reagent, they should be able to work out what products they are likely to get. Thus, they also should be able to evaluate any ‘anomalous’ result to determine whether the possible reactions will give such a result. This might prevent them from ‘inventing the right answer’ to replace the ‘anomalous’ results too readily.

The content framework of QA must be made explicit to students, that is, teachers must overtly specify the concepts, propositions, facts, process skills and strategies required for QA. Meaningful learning of QA can take place if students realise that they have to apply, and know how to apply the content knowledge that they learn in the classroom to the experiments that they do, as well as master the process skills required. Students also need to be aware of their own thinking (Costa, 1991), to be able to describe, monitor, evaluate and reflect on what they do in the practical sessions. As the students are novices in chemistry, the teacher has a responsibility to provide QA laboratory learning experiences which can facilitate such meaningful learning. Unfortunately, many teachers tend to neglect this responsibility because of the lack of time, and because such learning is not essential for students to do well in the practical examinations. 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, the nature of examinations has significant impact on implemented curriculum (Hodson, 1993), and 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.

References

Carr, M., Barker, M., Bell, B., Biddulph, F., Jones, A., Kirkwood, V., Pearson, J., & Symington, D. (1994). The constructivist paradigm and some implications for science content and pedagogy. In Fensham, P.J., Gunstone, R.F. & White, R.T. (Eds.) *The content of science: A constructivist approach to its teaching and learning* (pp. 147-160). (London, Falmer Press).

Chinn, C.A. & Brewer, W.F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research*, 63, pp. 1-49.

Cooley, J.H. & Williams, R.V. (1999). Qualitative analysis in the beginning organic laboratory. *Journal of Chemical Education*, 76, pp. 1117-1120.

Costa, A.L. (1991). The search for intelligent life. In Costa, L.A. (Ed.) *Developing minds: A resource book for teaching thinking*. *Volume 1* (pp. 100-105). (Alexandria, VA, Association for Supervision and Curriculum Development).

Duit, R., & Treagust, D.F. (1995). Students' conceptions and constructivist teaching approaches. In Fraser, B.J., & Walberg, H.J. (Eds.) *Improving science education* (pp. 46-69). (Chicago, Illinois, The National Society for the Study of Education).

Duit, R., Treagust, D.F., & Mansfield, H. (1996). Investigating student understanding as a prerequisite to improving teaching and learning in science and mathematics. In Treagust, D.F., Duit, R.,& Fraser, B.J. (Eds.) *Improving teaching and learning in science and mathematics* (pp. 17–31). (New York, Teachers College Press).

Fensham, P.J. (1994). Beginning to teach chemistry. In Fensham, P.J., Gunstone, R.F. & White, R.T. (Eds.) *The content of science: A constructivist approach to its teaching and learning* (pp. 14-28). (London, Falmer Press).

Fensham, P.J. & Kass, H. (1988). Inconsistent or discrepant events in science education. *Studies in Science Education*, 15, pp. 1-16.

Freedman, M.P. (1997). Relationship among laboratory instruction, attitude towards science, and achievement in science knowledge. *Journal of Research in Science Teaching*, 34, pp. 343-357.

Gilbert, J.K & Pope, M.L. (1986). Small group discussions about conceptions in science: A case study. *Research in Science and Technological Education*, 4, pp. 61-76.

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).

Gunstone, R.F. (1991). Reconstructing theory from practical experience. In Woolnough, B.E. (Ed.) *Practical science: The role and reality of practical work in school science* (pp. 67-77) (Milton Keynes, Open University Press).

Herron, J.D. (1996). *The chemistry classroom: Formulas for successful teaching*. (Washington, DC, American Chemical Society)

Hidi, S. (1990). Interest and its contribution as a mental resource for learning. *Review of Educational Research,* 60, pp. 549-571.

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review,* 70, pp. 33-40.

Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. *Studies in Science Education*, 22, pp. 85-142.

Johnstone, A.H. (1984). New stars for the teacher to steer by? *Journal of Chemical Education,* 61, pp. 847-849.

Johnstone, A.H. (1999). The nature of chemistry. *Education in Chemistry,* 36, pp. 71-73.

Johnstone, A.H. & Wham, A.J.B. (1982). The demands of practical work. *Education in Chemistry,* 19, pp. 71-73.

Marzano, R.J. & Pickering, D.J. (1991). Dimensions of learning: an integrative instructional framework. In Costa, L.A. (Ed.) *Developing minds: A resource book for teaching thinking*. *Volume 1* (pp. 94-99) (Alexandria, VA, Association for Supervision and Curriculum Development).

McDermott, D.P. (1988). Chemistry and the framework of learning. *Journal of Chemical Education,* 65, pp. 539-540.

Nakhleh, M.B. & Krajcik, J.S. (1994). Influence of levels of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching,* 31, pp. 1077-1096.

Pintrich, P.J., Marx, R.W., & Boyle, R.A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, 63, pp. 167-200.

Reif, F. & Larkin, J.H. (1991). Cognition in scientific and everyday domains: Comparison and learning implications. *Journal of Research in Science Teaching*, 28, pp. 733-760.

Rop, C.J. (1999). Student perspectives on success in high school chemistry. *Journal of Research in Science Teaching,* 36, pp. 221-237.

Skemp, R.R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching,* 77, pp. 20-26.

Tan, K.C.D., Goh, N.K., & Chia, L.S. (1999). Enhancing critical thinking in qualitative analysis in chemistry. In Waas, M. (Ed*.). Enhancing learning: Challenge of integrating thinking and information technology into the curriculum (Volume II)* (pp. 786-791) (Singapore: Education Research Association).

Tasker, R. & Freyberg, P. (1985). Facing the mismatches in the classroom. . In Osborne, R & Freyberg, P. (Eds.) *Learning in science: The implications of children's science* (pp. 66-80) (Auckland, London: Heinemann).

Tsoi, M.F. (1994). *Effects of different instructional methods on interpretation skills in chemical qualitative analysis*. Unpublished Master's Thesis, National University of Singapore, Singapore.

University of Cambridge Local Examinations Syndicate (UCLES). (1994). *Chemistry: Report on the November 1993 examinations* (Cambridge, Author).

University of Cambridge Local Examinations Syndicate (UCLES). (1995). *Chemistry: Report on the November 1994 examinations* (Cambridge, Author)..

University of Cambridge Local Examinations Syndicate (UCLES). (1996). *Chemistry: Examination syllabuses for 1999* (Cambridge, Author).

University of Cambridge Local Examinations Syndicate (UCLES). (1997). *Chemistry: Report on the November 1996 examinations* (Cambridge, Author).

University of Cambridge Local Examinations Syndicate (UCLES). (1998). *Chemistry: Report on the November 1997 examinations* (Cambridge, Author).

White, R.T. (1991). Episodes, and the purpose and conduct of practical work. In Woolnough, B.E. (Ed.) *Practical science: The role and reality of practical work in school science* (pp. 78-86) (Milton Keynes, Open University Press).

White, R.T. (1994). Dimensions of content. In Fensham, P.J., Gunstone, R.F. & White, R.T. (Eds.) *The content of science: A constructivist approach to its teaching and learning.* (pp. 225-262) (London, Falmer Press).

Zieger, H.E. (1993). Whether organic qual will wither? *Journal of Chemical Education,* 70, pp. 387-388.

Zubrick, J.W. (1992). W(h)ither organic qual*?* *Journal of Chemical Education*, 69, pp. 387-388.

TABLE I: Schools and composition of groups of interviewees (n=51)

School	Students	Total number of groups
R	(1,2), (3,4), (5,6), (7,8), (25,26), (27,28), (38,39), (40,41)	8
S	(9,10,11), (12,13), (14,15), (16,17), (18,19), (20,21,22), (23,24)	8
M	(29,30,31), (32,33,34), (35,36,37), (42,43,44), (45,46,47), (48,49), (50,51)	7

Note: The numbers in a bracket denote the students in each interview group, for example, (1,2) denotes that Students 1 and 2, from School R, were interviewed together.

TABLE II: Students' perception of QA and the difficulties that they encounter in QA practical work (n=51)

Students perceptions and difficulties	Number of students
1. QA is tedious, irritating, frustrating or difficult.	12
2. Did not know the purpose of the procedures or what results to expect after carrying out the procedures.	21
3. Testing for gases is difficult.	14
4. Making inferences from results.	13
5. Getting unexpected results, results that did not tally, or uncertain about the correctness of the results obtained.	26
6. QA involves mainly memory work.	14

Figure 1: Questions asked during the interviews

Students' feelings and attitude towards qualitative analysis

1. How do you find qualitative analysis?

2. What are your feelings about qualitative analysis?

Problems and difficulties faced

1. Do you find any aspects of qualitative analysis difficult?

2. Why do you find the aspects that you mentioned difficult?