ENHANCING GRADE 10 THAI STUDENTS' STOICHIOMETRY UNDERSTANDING AND ABILITY TO SOLVE NUMERICAL PROBLEMS VIA A CONCEPTUAL CHANGE PERSPECTIVE

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The international literature suggests students frequently resort to the use of formulae when solving stoichiometry problems without understanding the concepts. In prior work we identified Thai student alternative conceptions and ability to solve numerical problem for stoichiometry. The results indicate that many Thai students also hold alternative conceptions and that their ability to solve numerical problems is related to their understanding of the concepts. In the present work we describe an intervention consisting of the development of a series of *stoichiometry learning units (SLUs) based on a conceptual change approach. The units involve five steps: express ideas, share ideas, challenge ideas, accommodate ideas, and apply ideas. The SLUs were implemented by three volunteer teachers in three Grade 10 science classrooms from three different schools. The findings suggest that the conceptual change approach can be useful in addressing student alternative conceptions, developing student conceptual understanding, and enhancing students' ability to solve numerical problems.*

KEY WORDS: Grade 10 Thai Students, Stoichiometry, Numerical Problems, Conceptual Change.

Introduction

Stoichiometry is an important topic in chemistry and one of the concepts central to the learning of chemistry is the mole concept. Kolb (1978) commented that there was "probably no concept in the entire first year chemistry course more important for students to understand than the mole…one of main reasons the mole concept is so essential in the study of chemistry is stoichiometry"(p. 728). However, literature suggests that students frequently hold alternative conceptions for stoichiometry concepts, and that they often experience difficulties learning stoichiometry (BouJaoude & Barakat, 2000; Cervellati, Montuschi, Perugini, Grimellini-Tomasina & Balandi, 1982; Huddle & Pillay, 1996; Krishnan & Howe, 1994). It seems such learning difficulties occur in both Western and non-Western countries, including Thailand – the focus/context of the present work. Previous work by the authors revealed that many Thai secondary school students hold alternative conceptions for stoichiometry-related concepts and have difficulty solving numerical problems for stoichiometry (Dahsah & Coll, 2008; 2007). Some details of this prior work are now briefly outlined.

Our prior work involved administration of stoichiometry test items to 97 Thai Grade 10 secondary school students who had studied stoichiometry and related concepts as part of their normal schooling in the 2004 academic year. The test data suggested that less than half of the students surveyed could be described as holding a sound understanding of the concepts. The main alternative conceptions identified were: (1) students could not understand scientific concepts at the macroscopic (e.g., mole) or microscopic levels (e.g., molecules and atoms) and thought one mole was the same as one molecule; (2) most of the students thought one mole of all substances contained 22.4 dm^3 at standard - temperature and pressure and did not consider the different phases of substances (liquid, solid, or gas); (3) most of the students thought a solution that contains the greatest amount of solute is the most concentrated solution; (4) students thought the ratio of molecules was the same as the mass ratio of the substance; and (5) students thought the limiting reagent was the reactant present in the least mass.

In terms of students' ability to solve numerical problems, the students tended to use formulae without understanding the underlying concepts, and some used the formulae without understanding the formulae themselves. In addition, many students failed to attempt an answer – indicative of a lack of confidence (and presumably perceived competence) in solving these types of stoichiometry questions. The research findings also suggested that numerical problem-solving skills of these Thai students depended heavily on their conceptual understanding. Students who did not understand the related concepts in the questions were typically not able to solve numerical problems. Likewise, students who held alternative conceptions could sometimes 'solve' the problem or parts thereof, but without providing fully correct answers.

Generally the results of our prior work indicate that student understanding of the underlying stoichiometry concepts is important. Students who understood the concepts could better solve numerical problems, while students who did not fully understand the concepts or who held specific alternative conceptions could not solve problems correctly. Thus there is a need to develop learning activities that support student conceptual understanding rather than just coaching them to solve numerical problems using formulae by rote. The literature, particularly those associated with constructivist-based teaching suggests that an understanding of student prior conceptions provides useful insight into their thinking, and can facilitate teachers to devise pedagogies appropriate for their particular students (Bell, 1991; Taber & Watts, 1997; Tobin & Tippins, 1993). Based on the findings of our previous work a series of stoichiometry learning units based on a conceptual change approach was developed as an intervention for the teaching and learning of stoichiometry topics at the Grade 10 level in Thailand.

Research Aim

The overall aim of the stoichiometry learning units was to enhance Thai Grade 10 student understanding and ability in solving numerical problems in stoichiometry. Specifically, the research aim for this inquiry was to address the following question: *Do a series of stoichiometry learning units, based on a conceptual change approach, enhance Thai Grade 10 students' understanding of stoichiometry, and their ability to solve numerical problems?*

Theoretical Basis and Methodology for the Inquiry

The work reported here is an interpretive study, and employed a research design consistent with features of interpretivist research suggested by Guba and Lincoln (1989). The research also seeks to gain an in-depth understanding of the teaching and learning of stoichiometry in Thai Grade 10 school classrooms during one semester in which the series of SLUs was implemented. It also investigated how different groups of students learn, constructed their understanding and tried to solve numerical problems, and how the social and educational setting influenced these activities.

Thus, implementation of the SLUs was monitored by means of classroom observations and interviews with teachers and students. Video and audio recorders were used to capture data and these along with students' worksheets and students' reflective journals formed the data corpus. Students' understanding of stoichiometry and ability to solve numerical problems were explored after implementation of the SLUs using two previously validated purpose-designed questionnaires; the *Stoichiometry Concepts Questionnaire (SCQ)* and the *Stoichiometry Problem-Solving Questionnaire (SPQ)* (Dahsah & Coll, 2007; 2008). Data from questionnaires, observations, interviews and related documents were analysed thematically and the effectiveness of the SLUs was evaluated.

Developing the Stoichiometry Learning Units (SLUs)

The development of the SLUs for this inquiry was based on the guiding principles of the learning process stipulated in the *Thai 1999 National Educational Act* and its Amendments, namely, *The Second National Education Act, 2002* (Office of the National Education Commission, 2002). The units drew on constructivist-based learning and on conceptual change theory. The learning process in the SLUs is thus based on the assumption that learners come to class with their own prior-knowledge, and learning experiences. It further assumes that the interaction between the existing conceptions and new knowledge is an important part of learning, and that the learner constructs knowledge both individually and as a result of social interaction with others.

Hewson (1992) suggests that the purpose of the conceptual change approach is not to force students to give up their existing concepts in order to adopt scientific concepts, but to facilitate students in building a conceptual framework by modifying their existing conceptions with new knowledge. There were six aspects of the conceptual change approach that were used as guiding principles in the SLUs:

1. Students should be encouraged to develop their competence in science to meet students' interests and aptitudes to the best of their potential;
2. Prior knowledge is important for students in learning new knowledge, bearing in mind individual differences;
3. Social interaction can facilitate successful science learning, and as a consequence communicating ideas and group work are important in the learning process;
4. Teachers should act as facilitators who encourage students to fully develop their potential, and students must be actively involved in 'hands-on' and 'mind-on' learning activities, hence, the students' role is that of an active learner, and the teacher' s role is that of a facilitator of learning;
5. Productive science learning can be promoted by multiple, active and challenging learning activities using a variety of instructional materials. The activities can be used to create cognitive conflict in students who hold conceptions different to scientific concepts, but this must be provided in a supportive environment that helps students understand science concepts and how to represent the concepts using multiple modes of representation; and
6. Learning outcomes should be assessed using a variety of methods, such as observation of student behavior, learning procedures, participation in activities, examination of students' reports, journals, project work or portfolios, as well as tests of conceptual understanding.

The five steps of learning based on the conceptual change approach employed by Stephans (1994) were used to guide the learning process for each unit of SLUs. These were:

1. *Express Ideas*: students were activated through activities to formulate an outcome or prediction about a concept to identify their existing ideas;
2. *Share Ideas*: students were activated to discuss and share their stated prediction or outcome first with a partner, then with the whole class;
3. *Challenge Ideas*: students were activated through activities or experiments to test their predictions or observations, and to confirm their predictions;
4. *Accommodate Ideas*: students were activated to accommodate the concept by resolving conflicts between their existing ideas and their observations, and/or relating ideas to an appropriate context; and
5. *Apply Ideas*: students were activated to extend and apply the concept they have learned to solve meaningful problems and to use the concept in other situations.

The activities used in the SLUs emphasised 'hands-on' and 'minds-on' activities to help students understand science concepts, and provide a supportive environment to help students understand science concepts by representing concepts using multiple modes of representation. The units also sought to help students understand relationships between the different modes of representation as recommended in the literature (see, e.g., Johnston, 1990; Tasker & Dalton, 2006).

The learning outcomes for the SLUs were aligned with the learning outcomes of Thai science curriculum, and focused on three aspects of science learning: *conceptual understanding*, *science process* *skills* (with a focus on ability in solving problems), and *attitude-toward-science*. The main learning outcomes of the SLUs were to:

1. Understand stoichiometry concepts;
2. Design and conduct experiments, collect data, analyze data, interpret data, make conclusions, and present the finding about experiment stoichiometry;
3. Perform stoichiometry calculations for both easy and more complex problems;
4. Apply stoichiometry concepts to solve problems both in further education and everyday life; and
5. Use scientific process skills and scientific attitude in investigations and solving problems in everyday life.

The assessment regime used in the SLUs was also aligned with the assessment guides provided in the *Thai Basic Education Curriculum (B.E. 2544)* (Ministry of Education Thailand, 2002), and *Thai Science Curriculum (B.E. 2546)* (IPST, 2003). The *Basic Education Curriculum* suggests that the learning evaluation should assess in a way that informs all students' development, progress and achievement. It requires a variety of methods to be used to evaluate student conduct, behaviour, learning procedures, activities participation, and project work or portfolios. The methods must stipulate learning outcomes, and the assessment must evaluate group and individual learning so that the student can come to understand how to work in groups as well as individually. The specific assessment methods used in the SLUs were: evaluation of students' responses during discussion and presentations both in group and in whole-class settings; how they conducted the experiments; their participation in group activities; their use of worksheets; their ability to search and report material; tests and examinations; and their use of journals.

Initial SLUs were evaluated and subsequently revised after discussion with three volunteer teachers before implementation.

The revisions sought to validate the content and learning outcomes, identify activities for each unit, estimate the duration of the units, and to confirm the appropriateness of the units for their level and the school setting. The teacher-evaluators agreed that the learning outcomes, learning content, and assessment activities presented in the SLUs were consistent with the Thai science curriculum (IPST, 2003). They believed that the activities used in each unit would be interesting for both teachers and students. The teacher-evaluators also felt that the students using these SLUs would have more opportunities to construct their knowledge. However, they also felt that the learning processes using these activities would probably require more time in the laboratory and classroom than their normal classroom teaching (which was more didactic in nature).

The final version of the SLUs consisted of 16 units covering all the stoichiometry concepts identified in the Thai curriculum; atomic mass, average atomic mass, molecular mass, mole (molar mass, molar volume, and Avogadro's number), concentration of solution (% by mass, % by volume, % by mass/volume, molarity, molality, ppm, and mole fractions), preparation of solution, colligative properties (boiling point elevation and boiling point depression), chemical formulae, percent composition, chemical equation, the Law of Conservation of Mass, the Law of Constant Proportion, Gay-Lussac's Law of Combining Volumes, Avogadro's Law, quantity relationship in chemical reaction, limiting reagents, and percent yield. An example of one SLU - for the topic 'Limiting Reagent' is provided in Appendix A. This shows in detail how the topic was introduced, the teaching sequence, along with student and teacher activities.

Implementation of the Stoichiometry Learning Units

The SLUs were implemented by three volunteer teachers experienced in teaching chemistry at the high school level (for a total 27 years). The teachers were from different schools: one in Bangkok, the nation's capital city, and two in Nontaburi province, in a suburban area close to Bangkok. The three schools teach Grade 7 to Grade 12 (ages 13 - 18), and are large schools with school rolls of more than 3000, with about 40 - 50 students in a given class. Each teacher implemented the SLUs in their Grade 10 chemistry classrooms when teaching the stoichiometry topic in the second semester of the 2005 academic year (in Thailand, October 2005 - February 2006). There were 50, 48, and 45 students in each class.

A variety of pedagogical techniques were used in the implementation of the SLUs: concept mapping, writing about the concepts, conducting experiments, engaging in cooperative learning, use of analogy, demonstrations, and whole-class discussion. All of these activities aimed to promote students' learning for conceptual change. In addition, the techniques used were consistent with the context of learning including the teacher, students, content, and time constraints. An overview of the development and implementation of the stoichiometry learning units is presented in Figure 1.

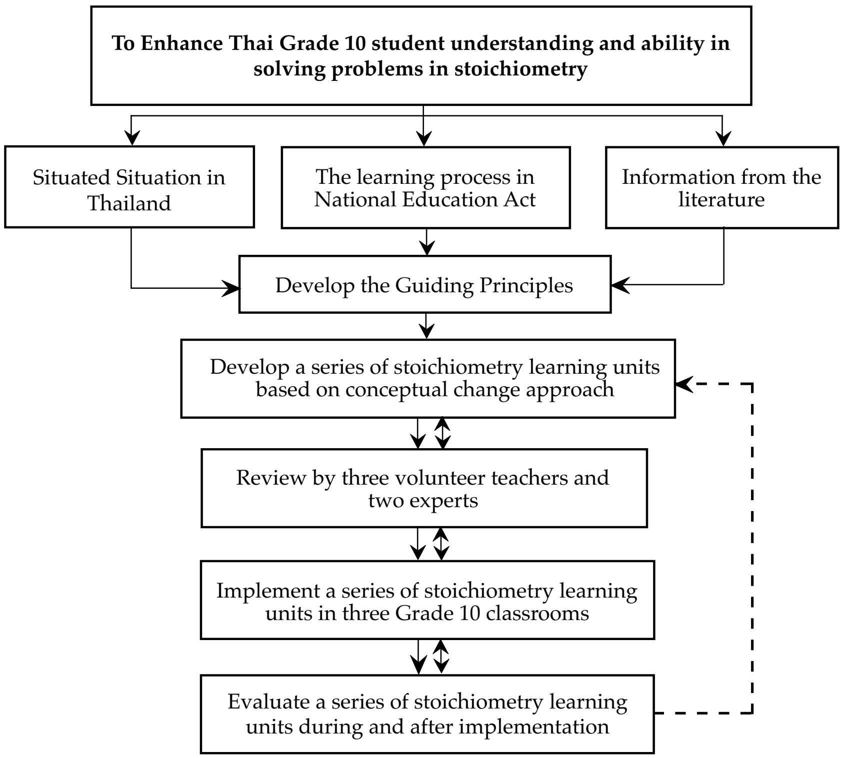

Figure 1. Overview of the Stoichiometry Learning Units developed in the study.

Results and Discussion

Teaching and Learning

The activities that the teachers used when teaching each concept were similar and included: (1) exploring student understanding using questioning, games, or demonstrations; (2) sharing students ideas by discussion in group or in a whole-class setting; (3) challenging student ideas using various activities such as experiments, demonstrations, discussion, games, and so on; (4) accommodating student ideas using games, concept mapping, discussion and questioning; and (5) applying ideas using calculations and everyday life examples.

The findings suggest that the techniques the students deemed most effective were experiments and discussion in group as students' reflection in journal writing, for example, "learning by doing laboratory and group work changed my attitude towards learning, I am happy with learning by sharing opinions in a group and doing experiments to understand the concepts". In addition, teacher questioning seemed to be the main strategy that helped students develop their conceptions. The examples of each technique are now discussed in the unit of conversation of mass and limiting reagent.

In the unit of conservation of mass, deemed the most effective unit (86% of the students held sound understanding) there were three experiments set for students. Each student in a group did one experiment, the student then came back to their original group and told their peers about their experiment (there were three students in each group). The experiments gave different results: one experiment produced a gas (from the reaction of baking soda with vinegar), one experiment produced a crystal (from the reaction of $KAlSO_4.12H_2O$ with NH_4OH), and the third reduced a blue solution and produced a sediment (from the reaction of Al foil with $CuCl_2$). The students were 'activated' with the questions to discuss the concept of mass in the reaction for each experiment in groups and in a whole class setting. From this unit, students were activated to do challenging experiments and engaged in group discussion to help them construct the concepts themselves. The findings suggest that the students could understand the concepts better.

For the unit 'limiting reagent', the teacher from school A, Nan (a pseudonym) used demonstration and questioning to activate students and challenge their ideas. She demonstrated the reaction of vinegar (acetic acid) and baking soda (sodium carbonate) to the class. During the demonstration she controlled the amount of acetic acid and varied the amount of the baking soda, and collected the gas produced in a balloon. To do this she set up six test tubes (numbered 1 to 6) that contained the same amount (0.01 mole) of acetic acid. She capped the test tubes with balloons that contained different amounts of baking soda: 0.0025, 0.005, 0.0075, 0.01, 0.0125, and 0.015 mole respectively. To focus the students on limiting reagents, she asked them to predict the amount of gas produced as represented by the size of the balloon once the reaction was complete.

Nan: Can you predict the size of balloon?

Student: If the amount of baking soda is greater, the size of the balloon should be bigger.

The teacher then mixed the baking soda with the acetic acid in each test tube and waited. The size of the balloons was bigger for each of the test tubes numbered from one to four. They were the same size for numbers four to six.

Nan: What has happened to the balloons? Why are the sizes of the balloons not bigger from number 4 to number 6?

Student: . . . . . .

Nan: What is in the balloons?

Student: $CO_{2.}$

Nan: Where does the gas come from?

Student: The reaction. CO_2 is one of the products [the students did this reaction in the unit on the Law of Conservation of Mass: $NaHCO_3 + CH_3COOH \rightarrow CH_3COONa + CO_2 + H_2O$.

Nan wrote the chemical equation of acetic acid and baking soda on the blackboard, and asked students to help her balance the equation.

Nan: What limits the amount of CO_2?

Student: Reactants.

Nan: In number one to number three, which reactant limits the size of the balloon?

Student: ……….

Nan then asked her students to calculate the mole of baking soda and vinegar in each test tube, and wrote the results on the blackboard. Next, she asked students again about the reactant that limits the size of the balloon.

Nan: In number one to number three, which reactant limits the size of the balloon?

Student: Baking soda.

Nan: How about numbers five and six?

Student: Vinegar.

Nan: Why?

Student 1: The least amount of reactant is limiting reagent.

Student 2: The reactant that runs out first is the limiting reagent, and the other reactant is in excess.

Nan: What does the limiting reagent mean?

Student: The used up reactant.

Nan: Used up?

Student: ……….

Nan: The used up reactant is the reactant that limits the amount of product that occurs that is why it is called limiting reagent. Why are the sizes of the balloons not bigger from number four to number six?

Student: Because they all contained the same amount of vinegar [the limiting reagent].

In this sequence the teacher used the demonstration as a focus of discussion for the concept of limiting reagents. The teacher questioning sought to prompt the students to think about the ideas that they held, the reactions they observed and the ideas from the discussion and to link these to scientific ideas of limiting reagents.

Student Understanding

Student understanding for the three classrooms after implementing the SLUs based on conceptual change approach was captured by the *SCQ* (see in Dahsah & Coll, 2008) and compared with the research findings from previous work which explored students who learned stoichiometry in normal teaching, a teacher described the concepts on the blackboard and let students perform calculations related to those concepts, most of the teaching time spent more on solving problems (Dahsah & Coll, 2008) (Figure 2).

The findings suggest that more students held sound understanding of stoichiometry concepts compared with those exposed to normal teaching. More than 70% of the students held sound understanding for the concepts of: molecular mass, number of entities in one mole, molar unit, conservation of mass, and limiting reagent. More than 60% of the students held sound understanding for the concepts of concentration, and molar mass. However, less than half of the students still did not hold sound understanding for the six main concepts of stoichiometry; mass, volume and number of entities relationships in chemical reactions, molar volume, atomic mass, concentration in molar unit, boiling point elevation and chemical equation. In addition, the same alternative conceptions found in the previous work were also found here, for example; one mole is one molecule (i.e. one mole of oxygen contains one oxygen molecule, one mole of S_8 contains eight atoms of sulfur because one molecule of S_8 contains eight atoms), the solution that contains greater amount of mole has higher concentration (1000 mL of 3 mol/dm^3 HCl has higher concentration than 400 mL of 5 mol/dm^3 HCl because in 3 mol/dm^3 solution has higher number of mole of HCl than 5 mol/dm^3 solution), etc.

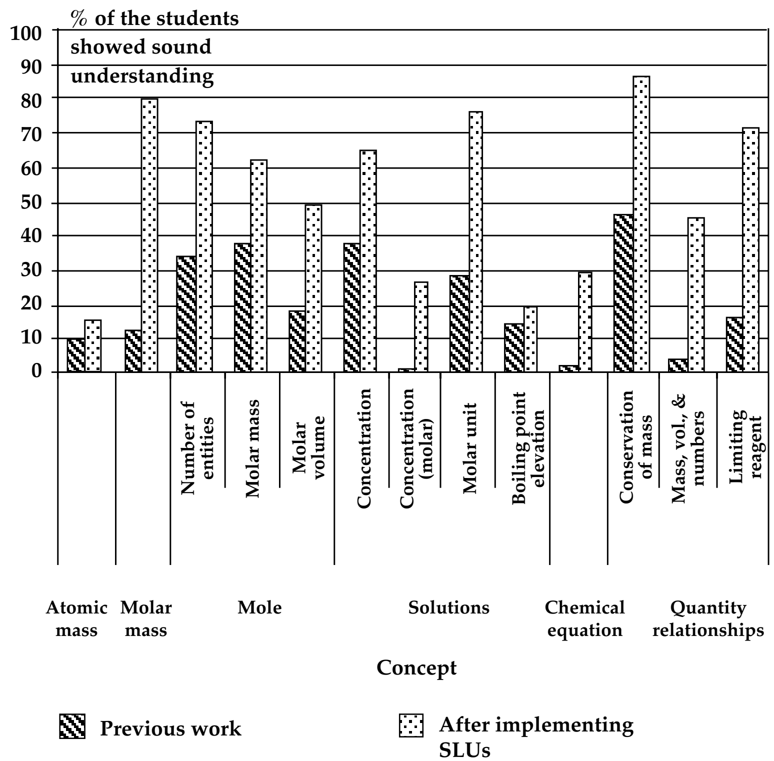

Figure 2. Percentage of students (%) with a sound understanding of stoichiometry concepts, after implementing the SLUs compared with previous work.

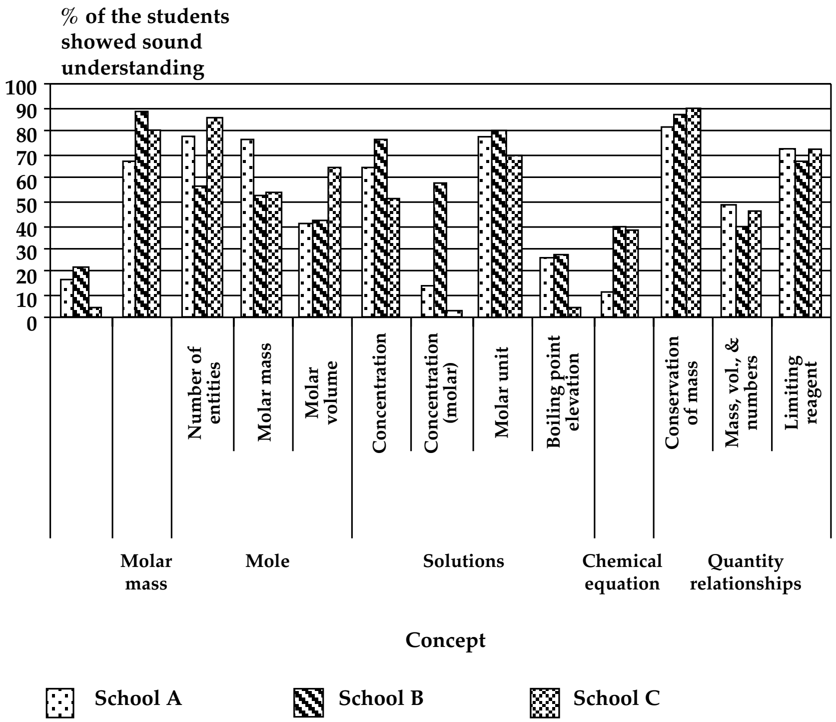

Figure 3. Percentage of students (%) with a sound understanding of stoichiometry concepts after implementing the SLUs, comparison of three schools.

The results from the three schools showed that the percentage of students holding a sound understanding in most concepts was similar, only few concepts were different (See Figure 3). All the schools were similar from the perspective of socioeconomy (large-size public schools) and classroom size (45 - 50 students), as well as, teachers' teaching experiences (a total 27 years). There were only two aspects that were different; students' achievement and students' learning. The students' achievement of students from School A and

School B were similar but both were much higher than School C (Figure 4). The results showed that students in School A and B performed better than the students in school C in certain specific concepts, namely; atomic mass, concentration, molar unit, and boiling point elevation, whereas students in School C performed better in concept of number of entities, molar volume, conservation of mass, and limiting reagent. This finding suggests that the student understanding after intervention was not due to differences in students' achievement across the three schools, but to the differences that might have occurred during the teaching and learning sessions.

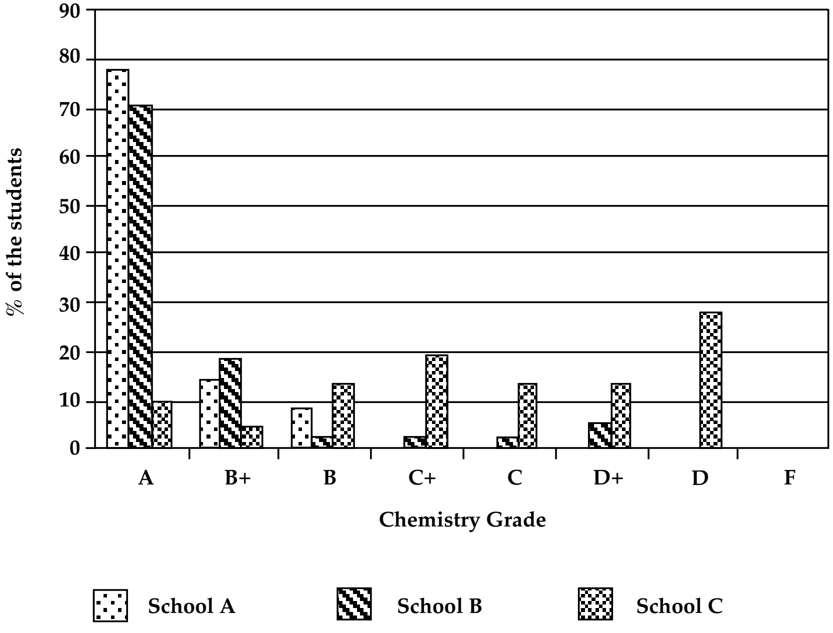

Figure 4. Students' (%) chemistry achievement in the first semester (before implementing the units) for schools A, B, and C.

Student Ability to Solve Numerical Problems

Student ability to solve numerical problems for stoichiometry topics also was explored using the SPQ. The details of this instrument can be found in Dahsah and Coll (2007). Essentially it comprised three open ended-questions involving: 1) calculating chemical formulae; 2) a problem regarding salt formation and limiting reagents; and 3) a problem in calculating the yield for the thermite reaction. (Appendix B)

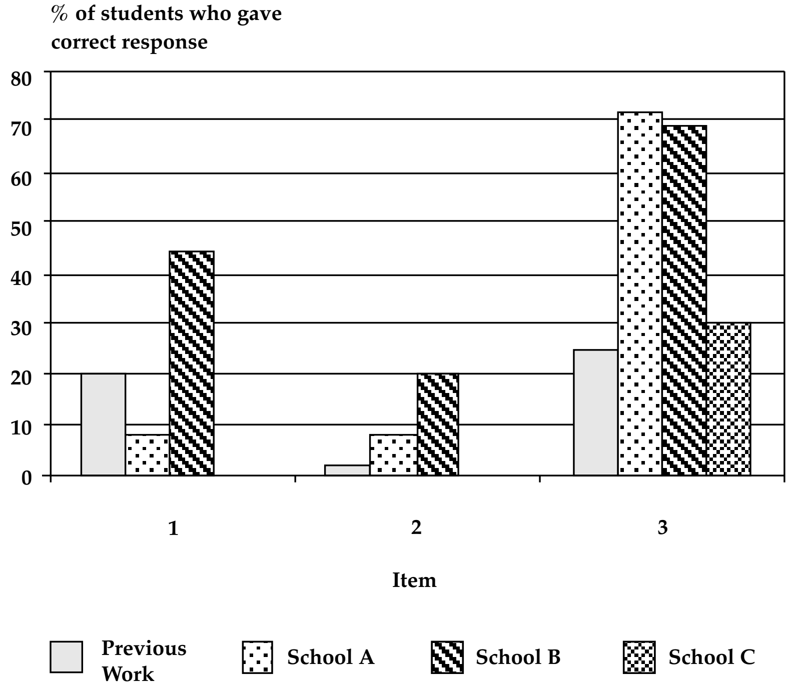

Figure 5. Percentage of students (%) with the correct response for the *SPQ* after implementing the units compared with previous work.

The findings here after the intervention whilst showing some improvement were not as good as might be expected (Figure 5). Students did well only in item 3 (balancing equation of given the equation, calculating the mass reactant, actual yield, and theoretical yield). In item 2, most of the students struggled with writing a formula of the product and balancing equation. In item 1 (the empirical formula question), the students were asked to decide if a white powder was heroin, meaning they needed to find chemical formula of the white powder or calculate the percent composition of all elements in white powder, and compare these with the formula for heroin. Most of the students compared only one or two elements and many did not even attempt the question. However, the authors noted that this was a rather difficult problem.

The results of the three schools were also different. School B gave better results than School A, and School A gave better results than School C (Figure 5). As discussed, the different results among the three schools were only students' achievement and students' learning. The lower number of School C students who were able to solve the problems might be the result of their academic achievement, but not for School A students. The academic achievement of School A was not different from School B. The difference between School A and School B in terms of the intervention was students' learning. In school B, students were seated in groups with most of the students actively discussing their ideas within the groups during the learning activities - especially when doing experiments and solving problems. Pracha (a pseudonym), for example, felt that the "SLUs are good units because students could learn through group activity, study and do experiments by themselves, try out their thinking, and make a conclusion. These could help students to understand the concepts more than learning by memorising" (Student Journal). In School A, most of the teaching used a normal classroom with a single desk for each student which the students prefer. Racha (a pseudonym) commented “I do not like to learn in a laboratory classroom because I cannot concentrate on the study when I sit in a group especially at the back of the room” (Student Journal). In addition, the teaching in School A focused more on solving problems on worksheets individually rather than group discussion. It is inferred that discussion in groups was an effective learning strategy that was used to enhance students’ ability in solving problem.

Most of the students in these three schools resorted to using the proportional method rather than the formula method when trying to solve numerical problems; which contrasts with the earlier study in which most students used the formula method. As Nan commented “It is very interesting that most of my students did not use the algorithm method [formulae method] when they solve stoichiometry problem, which most of the students usually use and they said proportional method is easy and more useful than algorithm method.” A typical student response for calculating the concentration of a solution is shown below.

Calculating the amount of solute in 755 ml of 0.430 M H_3PO_4

Proportional method:

0.430 M H_3PO_4 ; 1000 cm^3 of H_3PO_4 solution contains 0.430 mol of H_3PO_4

So 755 cm^3 of H_3PO_4 solution contains $\frac{755 \times 0.430}{1000}$ mol of H_3PO_4

Formula method:

$$\text{Mol} = \frac{MV}{1000} ;$$

Where, mol = number of moles; M = concentration in molar unit; V= volume in cm^3

So that $\text{Mol} = \frac{0.430 \times 755}{1000}$

(From: students’ response in problem-solving questionnaire Item II).

In addition, the results showed that if the students achieved the first two criteria of problem-solving skills: understanding the question and selecting the appropriate information or concepts to use in solving the questions, then they were able to calculate the correct answer. All students who held a sound understanding of the related concepts could arrive at the correct answer suggesting that mathematical skills alone was not a problem for these students.

Teacher and Student Views about the Teaching and Learning of Stoichiometry Using the SLUs

As noted above, the teaching and learning in the SLUs was based on a conceptual change approach. In this approach students' prior knowledge and social interactions were deemed important. Hands-on and minds-on activities were used to allow students to express their ideas, to foster conceptual conflict, and to encourage students to accommodate new ideas. Teacher questioning was very important to activate student thinking in group and class discussions aimed at enhancing student learning and helping students see and resolve their conflicts.

The interview with the teachers indicated that teaching using SLUs based on the constructivist-derived, conceptual change model-based pedagogies were very different from the norm in Thai classrooms which some of the teachers voiced their concern about. Ratree (a pseudonym of a teacher from School B), for example, noted she struggled to avoid transmissive teaching: "I almost told my students the answers many times when my students could not give me the correct answers on time". Likewise, the teachers struggled to avoid "jumping straight in" to numerical problem-solving issues, with Nan commenting: "I feel very nervous with my teaching because the teaching in SLUs are different from what I teach, and they take more time to teach the concepts, and I still think 'will my students have enough time to practice their problem solving?' "

However, after some initial concerns the teachers were soon happy teaching using the SLUs. They felt that the SLUs helped their students understand stoichiometry concepts better - as well as enhance student ability in solving numerical problems. For example, Nan commented: "I am happy that I used SLUs in my class. My students are also happy with the teaching and they also get the high achievement in the examinations - both concepts and problem-solving" [Teacher interview].

The teachers also felt that they had learned new teaching techniques through the use of SLUs, particularly about learner-centred teaching – a key feature of the new Thai science curriculum (IPST, 2003). In addition, the teachers found that the conceptual change teaching approach helps them understand their students better in terms of understanding their prior knowledge, and alternative conceptions. As Suree (a pseudonym for a teacher from School C) noted "I like the exploration activities in the SLUs such as analogy, demonstration, and questioning which could help me know my students' prior knowledge; not just quiz them" Ratree, likewise said "I did not understand student-centered teaching and I never agreed with it. Most of my peers just give students worksheet and ask students to work by themselves - which teachers call student-centered teaching. But after I used SLUs, I think I know it now, what student-centered teaching is ... I think I will use SLUs for my teaching next year and I will also use it as a guide to improve my teaching in another topic"

It was observed that most of the students enjoyed working, doing experiments and discussing in groups. They thought that learning in groups was not only helpful in constructing knowledge but also meant that they learned how to work in a group and increase unity in their groups. Natee (a pseudonym), for example, gained "an experience for learning in group work, helping and discussing with friends, doing and thinking together through the activities… I am happy with learning and I could understand the concepts better" [Student's Journal]. However, the hands-on and minds-on activities did require more time for the students to work in constructing their own knowledge, compared with lectures, especially for low achievement students. Thus, occasionally some steps of the teaching were omitted, especially the *apply ideas* step (the last step) that directly affects students' ability in solving problems. Hence, in *apply ideas*, students would have a chance to solve a variety of problems related to the concept which helped them understand the concept better and enhancing their ability in solving problems. Students who understand the concept took only a short time to solve the problem without prior practice but most of the other students the *apply ideas* step was important in order to help them solve the problems.

Conclusion

In summary, the five steps for the conceptual change approach that were used in the learning process were: *expressing ideas, sharing ideas, challenging ideas, accommodating ideas, and applying ideas.* The steps were implemented during the intervention that was composed of a series of stoichiometry learning units. Learning via these steps seemed to enhance students' understanding of the concepts. The research findings suggest that more challenging activities such as experiments and demonstrations, worked well when used to create cognitive conflict in students. Additionally, group discussion and teacher questioning seemed to be effective in helping students accommodate and reconstruct their ideas in a scientific way. While effective questions were able to guide students to think step by step, it is important for the teacher not to give students the answers. In addition, all five steps were deemed to be important in helping students confront their alternative conceptions, and reconstruct their conceptions. In the study, some stages were sometimes omitted, especially *apply ideas* because of time constraints. That was why some alternative concepts were also found and some students could not solve numerical problems related to those concepts.

The findings here suggest that it is first necessary to develop students' conceptual understanding before they are able to solve problems, similar to work reported by BouJaoude and Barakat (2000) and Tinger and Good (1990). Students especially younger students (e.g., at Grade 10) also needed time to practice their ability to solve numerical problems, especially in the case of complex problems, because they may not be able to define the questions or draw upon the relevant concepts. Thus, when teaching numerical problem solving, involving stoichiometry it is probably best if teachers teach students so that they clearly understand the concepts and that students be given time to practice numerical problem-solving.

Recommendations

This inquiry was an interpretive study. The study and its findings are thereby specific to its educational context. The researchers sought to provide sufficient description of the context, methodology, data analysis and interpretation, in order to enhance transferability of the findings. It is noted from literature that it is deemed more appropriate for the reader to judge the applicability of this research to his or her own educational context (Guba & Lincoln, 1994; Merriam, 1988). The following recommendations are thus best judged by the reader as to how they might impact upon his or her own educational setting.

Recommendations for Classroom Practice

According to the literature, stoichiometry is a difficult and complex topic for students to learn in chemistry. Many students in Thailand also experience difficulty in understanding stoichiometry. In order to understand stoichiometry in a manner acceptable to scientists and teachers (at this level of instruction) it is essential to help students develop their understanding and be aware of their alternative conceptions. Conceptual change was used in this work as part of the learning process in the SLUs with the role of the teachers shifting from the more traditional one of giving students ideas to facilitating students reconstruct their own ideas. The research here suggests that such a conceptual change based approach can help students better understand stoichiometry concepts and in combination with group work also enhance social interaction as reported in Liu (2004), Tepsuriyanond (2002) and Treagust, Chittleborough and Mamiala (2003).

Recommendations for Further Research

There is also a need in Thailand to help teachers understand the new paradigm of teaching encapsulated in the education reforms (Dahsah & Faikhamta, 2008). Teachers need to be exposed to modern models of learning and their associated pedagogies and how these models can be incorporated in their classrooms. It is not easy to change teachers' belief about their teaching, and to ask them to teach following new teaching approaches. However, in this research it seems that after implementing the SLUs, the teachers did change their teaching practices, when they felt that these new teaching methods worked in their classrooms. Hence, another recommendation that arise from this research is that if we wish to stimulate the development of teaching and learning in science then development programmes that allow teachers to experience the new models of learning and teaching and assessment processes are needed to help teachers become more accustom to, and become more enthusiastic about new pedagogies, thereby enhancing student understanding in the concepts.

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Appendix A

Stoichiometry Learning Unit: 14

Subject: Chemistry **Level:** Grade 10

Topic: Limiting Reagent **Time:** 3 Periods (150 mins)

Learning Outcome

1. Conduct an experiment to define the mole ratio of reactants and products in chemical reactions
2. Write chemical reactions from experimental data
3. Identify the limiting reagent when given more than one reactant in chemical reactions
4. Perform calculations of percent yield for an experiment

Science Concepts

1) All chemical reactions proceed according to the Law of Conservation of Matter and from balanced equations we can obtain the ratios of moles of reactants and products involved in a given chemical reaction, along with the masses and volumes of all reactants and products. These quantity relationships can be determined from the number of mole involved in a reaction, using the mole relationship
2) **The limiting reagent** in a chemical reaction is the reactant that is completely consumed. This reactant thus 'limits' the amount of product that can be formed, and determines the theoretical yield of the reaction. Other reactants are said to be present in excess, and
3) The **percent yield** of a reaction is the amount of product actually formed, divided by the amount of product calculated

to be formed theoretically assuming complete reaction and no loss, times one hundred.

$$\% \text{ Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

Learning Activities

Express and Share Ideas

1. Calculate the number of moles of products when given two reactants (Worksheet 1)

2. Predict the size of balloons of the reaction between baking soda and acetic acid when controls amount of acetic acid and varies amount of baking soda. (Teacher demonstration) Discuss responses with friends and in class.

   Before demonstration;

   - What will happen after mixing baking soda with acetic acid?
   - What makes the balloon blow up?
   - What is a chemical equation?
   - Can you predict the size of balloon?

   After demonstration;

   - What has happened to the balloons?
   - Why are the sizes of the balloons not bigger from number 4 to number 6?
   - What limits the size of the balloons (or amount of CO_2)?

Challenge and Accommodate Ideas

3. Do experiment with $NaHCO_3$ and CH_3COOH, determine limiting reagent and calculate percent yield for the reaction (Worksheet 2). [Activity I is the same as the demonstration]

4. Do 'Circle cut model' activity to define limiting reagent (Worksheet 3)
5. Present and discuss their result and conclusion

   After the discussion students should understand that:

   - limiting reagent is the reactant that limit the amount of products
   - In any chemical reactions, the mole ratio of the substance in the reactions equals the co-efficient number in balanced chemical equations
   - Actual yield is an amount of the product that actually formed, theoretical yield is an amount of the product that calculate to be formed (complete reactions), and

     percent yield is $\frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$

<u>Apply Ideas</u>

6. Perform calculations to determine limiting reagent and percent yield, and discuss

Instructional Materials

Worksheet and Laboratory equipment

Assessments

1. Students' response; discussion, presentation both in group and in class.
2. Do experiments
3. Group activity
4. Worksheet
5. Students' Journal

Worksheet I

Quantity Relationship in Chemical Reaction

To produce water from the reaction of hydrogen and oxygen gas, if we used 89.6 dm^3 of hydrogen gas completely react with 44.8 dm^3 of oxygen gas, 72 g. of water will be formed.

1. Write a balanced equation
2. Calculate the mole ratio of all substances
3. Do the mole ratio of the substances relate to the balanced equation? Explain
4. If you use 67.2 dm^3 of hydrogen gas react with 32 g. of oxygen gas. How many grammes of water produced? What is left over reactant, how much?
5. From Item 4, which reactant limits the amount of product produced?

Worksheet II

Limiting Reagent Experiment

Objectives

1. Study the reaction between $NaHCO_3$ and CH_3COOH
2. Find out the mole ratio of the reactants that completely react
3. Write the balanced equation from experimental data
4. Identify limiting reagent
5. Calculate percent yield of the reaction using experimental data

Pre-Questions

1. Write the chemical equation between $NaHCO_3$ and CH_3COOH
2. From the chemical equation in Item 1, could you tell the quantity relationship in chemical reaction? Explain

Activity I

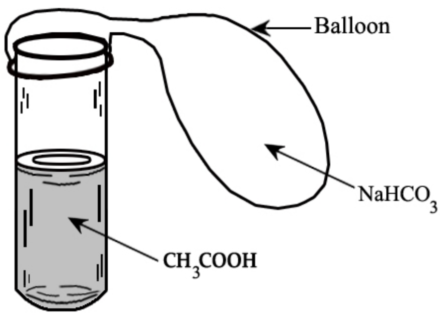
Limiting Reagents

Materials

Procedure

1. Use graduate cylinder to place 10 cm^3 of 1 M CH_3COOH into test tubes, label number on each test tube (1-6)
2. Label the balloons from number 1-6
3. Use filter paper weight 0.21 g of $NaHCO_3$ and then add to the balloon number 1. Careful, all $NaHCO_3$ should place on the bottom of the balloon
4. Repeat step 3, with add 0.42 g, 0.63 g, 0.84 g., 1.05 g., and 1.26 g. to the balloon number 2-6, respectively
5. Use tape to close the mouse of the test tube with the mouse of the balloon with the same number. Careful, do not mix reactant and make sure that no leak.
6. Pour the $NaHCO_3$ into the test tube make sure all reactants completely react. Observe and record the results
7. Measure the circumstance of each balloon, record the results

8. Draw line graph between circumstance of the balloon with amount of $NaHCO_3$ used



Results

Number	1 M CH_3COOH (cm^3)	$NaHCO_3$ (grams)	Circumstance of the balloon (cm)
1	10	0.21	
2	10	0.42	
3	10	0.63	
4	10	0.84	
5	10	1.05	
6	10	1.26	

What I observed

Post-Lab Questions

1. Complete the Table

Number	1 M CH_3COOH (cm^3)	# of CH_3COOH (moles)	$NaHCO_3$ (grammes)	# of $NaHCO_3$ (moles)
1	10	0.21		
2	10	0.42		
3	10	0.63		
4	10	0.84		
5	10	1.05		
6	10	1.26		

2. Which test tube gives the biggest size of balloons which using the least amount of $NaHCO_3$?
3. Which test tube that $NaHCO_3$ and CH_3COOH completely react? (no excess reagent) Explain
4. What is the mole ratio of $NaHCO_3$:CH_3COOH that completely react?
5. Write a balanced equation using the mole ratio in Item 3? Compare with the equation you wrote in Pre-questions, is it similar?
6. In test tube number 6, which reactant that limits the size of the balloons (gas produced)? Explain

Conclusions

Comments and Suggestions

Activity II

Percent Yield

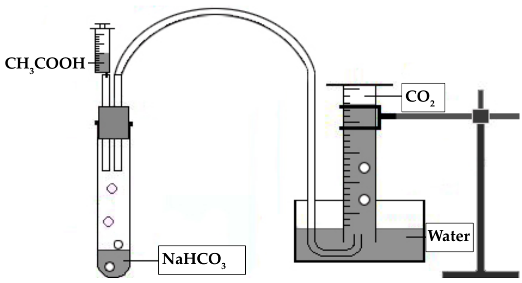
Materials

Procedure

1. Each group of the students select one of the experiment set in Activity I, table below

Set 1	M CH_3COOH (cm^3)	$NaHCO_3$ (grams)
1	10	0.21
2	10	0.42
3	10	0.63
4	10	0.84
5	10	1.05
6	10	1.26

2. Weight $NaHCO_3$, add to the test tube
3. Set the test tube with the gas collection set, see figure



1. Add 10 cm^3 of 1 M CH_3COOH into the test tube. Observe
2. After the reaction completely react, record the volume of gas produce

Results

Experiment Set: ______________________________

$NaHCO_3$ _____________ grammes = _____________ moles

1 M CH_3COOH _____________ cm^3 = _____________ moles

Volume of gas produced (actual yield) _____________ cm^3 = _____________ moles

What I observed

Post-Lab Questions

1. From the amount of reactant used, calculate volume of gas produced using mole relationship in a chemical equation (theoretical yield)
2. Calculate percent yield from;

   $$\text{percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

3. Could percent yield have a value over 100? Explain
4. What is the percent yield of the reaction following these situations;
   - Mass of $NaHCO_3$ you really used is more than what you record
   - Volume of gas produced you record less than the real volume
   - Concentration of CH_3COOH less than 1 M

Conclusions

Comments and Suggestions

Worksheet III

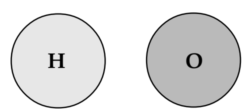
Who Limits?

Objectives

1. Give the meaning of limiting reagent
2. Identify limiting reagent from giving chemical reactions

Materials

Circle cut; 20 red and 10 blue



(Where red circle cut represents Hydrogen atom, and blue circle cut represents Oxygen atom)

Procedures

1. Make one molecule of hydrogen, oxygen, and water
2. Make molecules of water from giving number of hydrogen and oxygen molecules
3. Record your results in the Table

Results

Set	Hydrogen	Oxygen	Water	Excess Reactant
1	2	1		
2	2	2		
3	3	1		
4	3	2		
5	4	2		

Post-Activities Questions

1. In each set, which reactant limits the number of water molecules?
2. What is 'limiting reagent'?
3. To produce water from the reaction of hydrogen and oxygen gas, if we used 89.6 dm^3 of hydrogen gas completely react with 22.4 dm^3 of oxygen gas, 36 g. of water will be formed. Which reactant is limiting reagent?

Conclusions

Comments and Suggestions

Worksheet IV

Limiting Reagent and Percent Yield

Perform Calculation

1. Lead (II) Sulphide react with Hydrogen Peroxide produced Lead (II) Sulphate

   Chemical equation is $PbS + H_2O_2 \rightarrow PbSO_4 + H_2O$

If 63.2 grammes of PbS react with 48.0 grammes of H_2O_2

- Which reactant is a limiting reagent?
- How many grams of reactant excess?

2. $Al_2S_3 + H_2O \rightarrow Al(OH)_3 + H_2S$

   If 56.0 grammes of Al_2S_3 react with 48.2 grammes of H_2O

   - Which reactant is an excess reactant?
   - How many grammes of reactant excess?

3. Calcium (Ca) react with nitrogen gas (N_2) produced calcium nitride (Ca_3N_2)

   If 33.8 grammes of calcium react with 20.4 gramme of nitrogen gas

   - Which reactant is a limiting reagent?
   - If percent yield of this reaction is 72.4, how many grammes of calcium nitride produced?

4. Copper react with nitric acid, reaction is

   $3Cu + 8HNO_3 \rightarrow 3\ Cu(NO_3)_2 + 2NO + 4H_2O$

   If add 25.0 grammes of copper in excess nitric acid, 7.24 grammes of nitrogen monoxide produced, what is percent yield of this reaction?

5. Unbalanced equation: $As_4S_6 + O_2 \rightarrow As_4O_6 + SO_2$

   - How many grammes of oxygen need to react with 58.9 grams of As_4S_6?
   - If 41.2 grammes of SO_2 produced from the reaction above, what is a percent yield of this reactant?

6. Unbalanced equation: $CaCN_2 + H_2O \rightarrow CaCO_3 + NH_3$

   5.65 grams of $CaCN_2$ react with 12.2 grams of H_2O, what is the volume of NH_3 produced; if percent yield of this reaction is 86.0? (at STP)

Appendix B

Stoichiometry Problem-Solving Questionnaire (SPQ)

Description: Please complete all the following questions showing your calculations.

1. Some police officers confiscated a packet of a white powder, which they believed contained heroin. Purification of a sample by a forensic chemist resulted in a 38.2 mg sample for combustion analysis. This sample produced 94.4mg of CO_2, and 20.81mg of H_2O. A second sample was analysed for its nitrogen content, which was found to be 3.8%. Are these data consistent with the empirical formula for heroin ($C_{21}H_{23}O_5N$)?

   (Atomic mass of H =1, C = 12, N = 14 and O = 16 g/mol).

2. A sample of 35.25 g of solid strontium hydroxide ($Sr(OH)_2$) reacts with 755 mL of 0.430M phosphoric acid (H_3PO_4). This results in the formation of a new salt compound, and water.

   (Atomic mass of H = 1, O = 16, P = 31 and Sr = 87.6, Density of water = 1 g/cm^3)

   a. Write the complete, balanced chemical equation for this reaction

   b. Determine the limiting reactant

   c. How many grammes of the new solid compound are formed?

   d. What volume of water is produced?

3. Over the years, the thermite reaction has been used for welding railroad rails, in incendiary bombs, and to ignite solid-fuel rocket motors. The equation for the reaction is:

   $Fe_2O_3(s) + Al(s) \rightarrow Fe(s) + Al_2O_3(s)$

   (Atomic mass of O = 16, Al= 27 and Fe = 55.8 g/mol)

   a. Write a balanced equation for the reaction

   b. What masses of iron (III) oxide and aluminium must be used to produce 15.0 g of iron?

   c. What is the maximum mass of aluminium oxide that could be produced?

   d. How much aluminium oxide would be produced if the yield is 93%?