THE INFLUENCE OF STUDENTS' CONCEPT OF MOLE, PROBLEM REPRESENTATION ABILITY AND MATHEMATICAL ABILITY ON STOICHIOMETRY PROBLEM SOLVING

Hafsah, Taha
[1]Department of Chemistry, Faculty of Science and Mathematics,
Universiti Pendidikan Sultan Idris
Perak, Malaysia.

Rosnani, Hashim
[2]Institute of Education, International Islamic University Malaysia
Selangor, Malaysia.

Zurida, Ismail
[3]Faculty of Education, University Sains Malaysia
Pulau Pinang, Malaysia.

Kamaruzaman, Jusoff
[4]Faculty of Forestry, University Putra Malaysia, Serdang
Selangor, Malaysia.

Khoo Yin Yin
[5]Department of Economy, Faculty of Economy and Management,
Universiti Pendidikan Sultan Idris
Perak, Malaysia.

Abstract
Students' success in stoichiometry problem solving depends mainly on their understanding of the concept of mole and conceptual understanding of the problems. The challenge of enhancing students' performance in solving stoichiometry problems remain a daunting task as many resort to just teaching how solve stoichiometry problems algorithmically. Two purposes of this study are: first, identifying the major factors influencing students' performance in stoichiometry problem solving and second, investigating problems faced by students and teachers in stoichiometry learning and teaching in the classroom. A mixed method research design was employed in this study which involved a test and interview protocols. To conclude, students' understanding of the concept of mole and their problem representation ability are significant predictors, however mathematical ability is not a significant factor in determining students' success in solving the problems. Students have difficulties in 'making sense' of the chemical reaction itself. This implies teachers should not practice the 'short cut' approach in the entirety. Students ought to be exposed and guided to understand the underlying conceptual foundation of stoichiometry before introducing the algorithmic way of solving the problems.
Keywords: stoichiometry problem solving; mole concept; problem representation ability; mathematical ability.

Introduction

Stoichiometry is an important part of many practicing chemist's work. It is a topic in chemistry that calculates the quantity of a product that can be obtained from a reaction by assuming that the reaction is the only one involved and that the entire product is collected (O. Daley Jr. & O'Malley, 1988). It cuts across many sub disciplines of chemistry such as analytical chemistry, physical chemistry and organic chemistry. Hence, the instruction of stoichiometry problem solving is considered an essential part of the curriculum for chemistry students.

Students who do not fully understand the mole experience difficulties in understanding the subsequent topics (Musa, 2009). Especially, in stoichiometry problems since the calculations revolve around the mole concept. Stoichiometry calculations have been considered difficult by students in general chemistry (Hanson & Wolfskill, 1998). This is due to the many different facets a student must master, such as the mole concept, balancing chemical equations, algebraic procedures, and interpretation of a word problem into mathematical equations that serve as procedural steps which would then lead to the correct answer. Case and Fraser (1999) has shown that students have acute difficulties in dealing with the abstract concepts required of them to perform stoichiometric calculations using the mole concept. They also found that for students to solve stoichiometric problems, they must also be able to apply a thorough understanding of the principles involved in mole ratio and proportion calculations.

From the literature, one of the most commonly used tools to solve stoichiometry problems is dimensional analysis (To′th dan Sebestyén, 2009). This method involves analysis of mole, molarity, volume or mass of reactants. However, there are several other methods designed and developed over the years to help students overcome the difficulties solving these types of chemistry problems (Poole, 1989; Krieger, 1997). Proportional reasoning method and the mole ratio flow chart method (both involve mole ratio understanding) are also among the most known methods employed to solve stoichiometry problems (Wagner, 2001). While all of these methods have been useful in the author's classroom, none seemed to offer meaningful ways for helping students to really understand reaction stoichiometry calculations.

To improve the problem solving skills of students, it seemed that instructors must first focus on developing students' knowledge base and skills base. Without these, students could not succeed in true problem solving. Heavy emphasis should be placed first on conceptual understanding of topics; then maybe the secondary emphasis should be placed on carrying out and completing drills and exercises.

Literature review

Stoichiometry teaching

The literature indicates quite a number of studies investigated effective teaching strategies for the topic (Gabel & Sherwood, 1984; Bunce, Gabel & Samuel, 1991; Case & Fraser, 1999). However, these studies seemed to focus on algorithmic methods in solving stoichiometry problems. Davidowitz, Chittleborough and Murray (2010) insisted submicro diagrams being used as tools for reasoning in solving chemical problems, in teaching chemical equations and stoichiometry.

Gauchon and Méheut (2007) studied the impact of teaching stoichiometry on students' conceptions. They have the conception both reactants are totally converted is quite strong in those problems where reactants are in the same physical state, and is more in competition with the conception: only one reactant is totally converted when the reactants are in a different physical state.

Gabel and Sherwood (1984) reported that the 'factor label' method (matrix) is the most effective method, whereas the 'proportional' method (mole ratio) is the least effective. On the other hand, Wagner (2001) found that there was no statistically significant difference in students' performance on reaction stoichiometry between the DA (dimensional analysis teaching method) group and the MRFC (mole ratio flow chart method) group. Only one study reported that the use of tangible objects and thoughts experiments did have an impact on students' conceptual understanding on the subject (Case & Fraser, 1999).

Ashmore, Frazer, & Casey, (1979) proposed a model of problem solving that involves four stages. Identifying the problem is the first stage in the model. At this stage, students are expected to restructure a given problem into smaller problem statement. Next, is to select relevant information from memory. Here, students are expected to relate the information given with the question. Then, the third stage, students need to use the relevant information, to solve the problem. To this end, students are required to perform mathematical operations or deductive reasoning.

Students' difficulties with stoichiometry

Many studies show that students have trouble understanding the concept of the mole, concentration, molar mass, the mass of material, chemical equations and the limiting reagent (Frazer & Servant, 1987; Lythcott, 1990; Schmidt, 1990; Heyworth, 1999; Chiu, 2001; Meor Ibrahim, Ambrose, & Ling, 2003; Dahsah & Coll , 2007; Noraihan, 2008). In an investigation involving French grade 10 students, Laugier and Dumon (1990) (cited in Huddle & Pillay, 1996) analysed students' answers during a teaching sequence concerning reactions between two solutions: sodium hydroxide and copper sulphate. They reported that 88% of the students thought that there are neither copper ions nor hydroxide ions left at the end. For these students, all the ions have reacted; they did not envisage a possible surplus of a reactant in such a case. Another study using questionnaires about limiting reactants (Gauchon 1992, also cited in Huddle & Pillay, 1996), found that 68% of the students (grade 10 or later) said that the reaction between chalk and hydrochloric acid solution stops when there is no more chalk, whatever the quantities of chalk and hydrochloric acid. So, it seems that when beginning to learn about chemical reactions, students explain and interpret the final state of a chemical change in different ways, depending on experimental situations.

A case study conducted by Meor Ibrahim, Ambrose, and Ling (2003) on 18 students of Chemical Education Degree, reviewing student achievement on mole concept and the concept of matter and its effect on problem solving ability stoichiometric. The results showed that only 22% of the students understand chemistry concepts which is 6% to the concept of atoms, 6% are able to understand the concept of molecules, and 11% understand ion with the right concept. For the mole concept and its relationship to the equation, the achievement of conceptual understanding of the respondents was very poor.

Dahsah and Coll (2007) reviewed the achievements of 97 students from three secondary schools in Bangkok, Thailand, through questionnaires. Their study found that only 2% of the total respondents were able to understand all of the concepts tested on the chemical formula, chemical equations, the mole, molarity of solution, the limiting reagent, and the mass of the reactants. It is supported by the findings obtained by Noraihan (2008) in which a study was conducted on 70 form four students in three schools in the district of Mersing. The study which also used questionnaires showed that students experience difficulties in solving problems related to mole concept because they cannot relate the mole to the number of particles, the mass of substance and chemical equations.

Problems with mole ratios

Case and Fraser (1999) underlined another level of understanding among first year university students. They noted that students can be inclined to use a ratio equal to one between the amounts of matter of reactants whatever the transformations. It seems that these students have developed some idea of proportion between reactants but they can't consider any other ratio but one. Is this only due to the incapacity to use another ratio or is this linked with previous conceptions about chemical changes? These examples suggest different levels of understanding of stoichiometry. It seems that this notion needs to be built step by step, probably against strongly established conceptions.

In another study, Laugier and Dumon (1990) (cited in Huddle & Pillay, 1996) implied that when students feel the need to take into account proportions in a chemical change, some difficulties may appear. Spontaneously, they think of 'appropriate' volumes or 'appropriate' masses. They failed to understand that the quantities to be taken into account are amounts of matter that implies the use of the mole concept. Another group of researchers, Case and Fraser (1999) also noted that even among first year university students, a lot of mistakes in problem solving are due to confusion between different chemical quantities. Concentration, mass or volume is often used instead of the amount of matter.

Dahsah and Coll (2007) show that students have an alternative framework that related to the mole ratio of the mass ratio, the limiting reagent as the reactant with the smallest quantity in the form of mass and not the mole, and are using mol ratio of 1: 1 for all reactants.

Stoichiometry and balancing equations

In a study, Yarroch (1985) noted that 27% of students succeeded in solving stoichiometric problems, and 22% (of the total) interpreted and correctly used balanced equations, inferring that successfully writing a balanced equation and in interpreting correctly stoichiometric coefficients provides the basis of success in solving problems.

Niaz and Lawson (1985) reported students' difficulties in correctly interpreting a balanced equation. The different representational levels included in a balanced equation are very difficult to distinguish for students. For example, in the multiple choice tests given to them, the grade 10 students found it hard to understand that just one script, the balanced equation, can represent many experimental situations. Thus, at the end of a chemical change, students were surprised to find compounds that did not appear in the right hand side of the balanced equation. The authors also warned teachers that some students consider that chemical equations implied the use of stoichiometric quantities of reactants only. Moreover, they stressed that balanced equations may make students interpreted the chemical equation at a microscopic level only.

Mathematical ability in stoichiometry

Wink et al. (2000) conducted the MATCH program. It was a preparatory chemistry and intermediate algebra curriculum. They used integrated curriculum and text that include core material for standard preparatory chemistry and key algebra topics. The program revealed several advantages of an integrated curriculum. One example involves the benefits of developing unit conversion or dimensional analysis methods by discussing their roots in direct variation. Direct variation, $y \alpha x$, means that we can relate two variables by the equation $y = kx$. The 'k' is referred to by mathematicians as a constant of proportionality, but by chemists as a conversion factor. Such factors are commonly used in molar mass, Avogadro's number, etc. Approaching diverse problems from a simple basis in mathematics seemed to render instructions more efficient and students more adept at transferring calculation skills. In this manner, many of the calculations involved in stoichiometry problems are given a common conceptual basis, an important ingredient if we want students to transcend algorithmic problem-solving with a qualitative understanding. The explicit link between mathematics and chemistry in the MATCH program seemed to produce the desired outcome. When MATCH students later took chemistry courses they did better than their colleagues who took the conventional preparatory chemistry course.

Schmidt and Jignéus (2003) employed semi structured interview in their research and found that students used a non- mathematical strategy to solve an easy question. However, in moving from an easy-to-calculate problem to a more difficult one most students calculated the mass fraction or the percentages of an element in a compound. In this form the strategy comes close to the non-mathematical strategy. It is suggested for introductory chemistry courses to use easy-to-calculate problems and to concentrate on both the non-mathematical and the mass fraction strategy.

Surprisingly, despite the belief that mathematical ability has a strong influence on students' ability in stoichiometry problem solving, not many studies could really prove this. Nevertheless, the present study intends to explore the relationship between the two variables, focusing on students' algebraic mathematical ability and their effect on the performance of stoichiometric problem solving.

Problem Representation Ability

Experts are better problem solvers because they construct richer, more integrated mental representation of problems than do novices (Chi & Bassock, 1991). It is believed that problem solvers need to construct some sort of internal representation (mental model) of a problem in order to solve it. This personal problem representations serve to guide further interpretation of information about the problem, simulate the behaviour of the system based on the knowledge about the properties of the system, and triggering a particular solution schema (procedure) (Jonassen, 2003). Bodner and McMillen (1986) believed that students must disembed relevant information from a question and restructure the problem. 'Restructure' here means the modification of objects, operators, constraints as well as the initial and final states. This belief seemed to be true in solving stoichiometry problems. Researchers (Staver & Jacks, 1988; BouJouce & Barakat, 2000) indicated that students must be able to translate the worded problem of a stoichiometry problem into a balanced chemical equation and then use the appropriate mathematical equation, before solving the problem. In one study, Schwartz (1971) found that 'matrix representation' (a method to represent chemistry problem by dissecting the information given in columns or boxes) has the most significant effect on internal problem representations. It was substantially superior to grouping, graphs, and sentences because they allow for clearly defined needed information, suggest orders of operations, and provide consistent checks for partial solutions to be seen. Schwartz's finding was consistent with Gabel and Sherwood's work on the 'factor label' (matrix) method, which revealed that students engaging the matrix method showed better performance than the control group in solving stoichiometry problems.

In short, teachers may present qualitative problems in many forms and organizations. Nevertheless, it is important to note that qualitative representations support the solution of quantitative problems. Successful chemical problem solving requires both qualitative and quantitative reasoning (Ploetzner & Spada, 1998). Hence, training students to recognize and qualitatively represent problems could improve students' problem-solving performances.

The purpose of this study was two-pronged in nature. First, it attempted at identifying the major factors influencing students' performance in stoichiometry problem solving. By doing so, this study also tried to determine whether the major factors identified by the researcher constituted a solid ground for stoichiometry teaching. Second, the present study aimed at probing problems faced by students and teachers in stoichiometry learning and teaching in the classroom.

Methods

The study employed a mixed method design. It engaged both quantitative and qualitative approaches. The quantitative part of the study was designed to measure how students' performance in stoichiometry problem solving (PS) was affected by the three variables; understanding of the concept of mole (C), problem representation ability (PR), and mathematical ability (MA). A self-contructed written test comprised of 14 items (validated by an expert chemistry teacher and a chemistry lecturer from a local university) was the instrument employed to conduct the stepwise MRA to analyse the contributions of the three variables on PS and to seek out the best predictor.

This study also employs the interviewing methods to address the qualitative research questions. A set of written interview questions, a verbal interview and a think-aloud interview were constructed (validated by two experts from two local universities) to address the qualitative aspects of the research questions. These structured and semi-structured interviews were designed to elicit specific answers from the respondents. The written interview was constructed to gauge students' views on stoichiometry problem solving and the verbal interview was constructed to probe the teachers' views on the subject. The think-aloud interview however, was designed to probe students' conceptual understanding of the problems and it also served to identify the algorithmic and conceptual problem solvers.

The population of the study comprised five classes of Form Four science students of an urban secondary school in Selangor, Malaysia. The school had five pure science classes with a total of 212 students. Form Four students were selected as respondents because the topic of stoichiometry was taught in the second semester of that academic year. Form Four students were also selected because they were non-examination class. This means easier access to the students and less disruptions to the school schedules and time-table. The gender ratio of the population is almost 1 to 1 with the actual ratio of male to female being 113:99 or 1.14:1. This serves as an advantage to the research as it can reduce the 'gender effect' on the results. Since the researcher also taught all the five classes herself, it is also hoped to eliminate the 'teacher effect' on the results.

Stevens (1996) suggested, in MRA, if the probability of making the correct predictions (ρ^2) is set at 0.50, loss of predictive power tolerated at 0.05 (€) and power at 0.80, it is estimated that n = 36 per predictor for a study that involves three predictors. That means the minimum number of respondents should be 108 for three predictors. Thus, the researcher included 108 respondents in the study; i.e. by using the systematic random sampling method, by ticking every secondth student from all the five class registers.

Ten students were randomly selected from the 108 students as respondents for the written subjective questions and think-aloud interview. These ten students were selected by randomly selecting two students from each of the five classes. All five chemistry teachers from the school were interviewed for their perceptions on stoichiometry problem solving. The subjective test was designed to test students' understanding of the concept of mole, students' ability on problem representation, their algebraic mathematical ability and the students' overall performance on stoichiometric problem solving.

Prior to constructing the test, an in-depth study on the variables involved in the study was done to estimate content validity of the test. The test was then validated by an expert teacher from a renowned smart school in Selangor and validated again by two experts from local universities. The reliability of the subjective tests was estimated by engaging the tests of correlation coefficient of the Spearman rho (r = 0.918). This was done by appointing two distinguished examiners (experienced chemistry teachers) to score the pilot tests according to the marking scheme and then the researcher correlates between the two examiners.

The think-aloud interview comprises three stoichiometry problems. Respondents were requested to solve the three problems aloud and while doing so, the researcher was able to probe their understanding of the concept of mole, their conceptual understanding of the problems and difficulties encountered while solving them. The reliability of the instruments was estimated by taking every possible precaution against biases and 'over interpretation' of data. Students were asked not to write their names on the paper. This was done as the researcher taught all the respondents herself. When interviewing the teachers, the researcher made sure it was done formally, in a secluded area where the researcher and the interviewee would not be disturbed. In the think-aloud interview, one or two other chemistry teachers were also present and taking down notes during the interview. Thus, the researcher was able to confirm with the other teachers of what has been written in her notes and clarify things that were not very clear to the researcher. This method of triangulation has been adopted to control biases and establishing valid propositions or evaluation of the findings (Patton, 2001).

A pilot study was conducted prior to the test to identify problems that might arise from the instrument. Two pilot tests were carried out on 10 students to identify mistakes in the questions and to eliminate any items that may confuse the respondents. Specifically, it was intended to further evaluate the clarity of the instrument from the respondents' perspectives in terms of items construction and face validity. In addition, the pilot study allowed the researcher to identify the construct validity and the internal consistency of the instrument.

The subjective test was administered by the researcher with some help from four chemistry teachers of the same school. Arrangement was made with the other chemistry teachers so that all respondents of the five classes could sit for the test simultaneously to reduce missing respondents. Students were already told the goals of the research and participation was voluntary. It was made clear that confidentiality of responses was respected and participation or lack of participation will not influence their grades in the final school examinations.

The written interview questions were given right after the test. Ten randomly selected students from the five classes were requested to go to the chemistry laboratory after the subjective test to answer the questions. Again, here the researcher reminded all respondents, they were not required to write their names on the paper, that participation is voluntary, and they were free to go if they did not want to answer the written interview questions. None of them seemed anxious to go so the researcher proceeded with the written interview. All of the ten students answered the interview questions simultaneously. Since some of them answered the question very briefly, the researcher also gently probed and encouraged the respondents to be more elaborate in their answers.

The verbal interview on the five teachers however, was carried out at the respective schools of the teachers. While setting the date for the interview, the researcher informally asked for their consent to participate in the study and informed them that the confidentiality of their responses would be respected. The teachers were then engaged in formal interviews at their respective schools after school hours. The researcher made some arrangements to have the interview in a secluded area where she, her assistant (another chemistry teacher) and the interviewee would not be disturbed. The researcher was the sole interviewer but both she and the other chemistry teacher took down notes during the interview for the purpose of triangulation of data. To eliminate the probability of mistaken auditability, sometimes the researcher showed her notes to the interviewee to check the transcriptions and to determine the accuracy of the responses recorded.

The think-aloud interviews of the students were carried out in the chemistry laboratory of the schools after the school hours. Ten randomly selected students (with at least 2 students from each class) were selected for the interview. One or two other chemistry teachers were also present during the interviews. Again, the same method of triangulation was employed here. The two chemistry teachers acted as the researcher's assistants by taking down notes during the interview. Sometimes the researcher showed her notes to the interviewee to check whether she had heard and written the correct responses.

The students were given three stoichiometry questions to answer. During the problem solving exercise the respondents were requested to explain what they were doing. The researcher used the probing questions to encourage the students to say out whatever they were thinking, what went in their minds when they were solving the problems. Since the researcher hoped that the respondents would elaborate their answers, the interview was done in a relaxed atmosphere and the interviews were started with some general questions. Sometimes when the students seemed quiet or at a loss on what to do, they were prompted with some remarks or questions. Based on the predetermined probing questions, the interview was casually led to the research questions and the researcher just took notes discreetly and did not use any tape recorder to minimise any uncomfortable feelings that may arise from the unusually long conversation. After that the researcher carried out triangulation with the other two chemistry teachers.

Results and Discussion

All the variables, understanding of the concept of mole (C), problem representation ability (PR), mathematical ability (MA) and students' performance in stoichiometry problem solving (PS) were analysed to determine the strength of the predictors' ability in explaining the variations in students' performance in stoichiometry problem solving (the criterion).

Table 1 shows the summary of correlations between predictors and the criterion, and among the predictors selected. An inspection of the table indicated that students' performance in stoichiometry problem solving (PS) is highly positively correlated with their understanding of the concept of mole (C) ($r = .782$), problem representation ability (PR) ($r = .897$) and mathematical ability (MA) ($r = .743$). However the Model Summary, that is presented to highlight the practical importance of the model, suggested that 84.1% of the variance was explained only by two predictors, namely C and PR. MA was then removed from the model. The high value of R square (0.841) supported the overall fit of the model. The value of R square here indicates it is a strong model.

Table 1

Inter-Variable Correlation, Means and Standard Deviations for predictors and criterion (4 variables)

	PS	C	PR	MA
Pearson Correlation PS	1.000	0.782	0.897	0.743
C	0.782	1.000	0.726	0.809
PR	0.897	0.726	1.000	0.733
MA	0.743	0.809	0.733	1.000
M	2.01	5.57	2.36	4.96
SD	2.257	2.996	2.708	2.665

*Statistically significant at $\alpha = .05$
*N = 108

*C - understanding of the concept of mole
PR - problem representation ability
MA - mathematical ability
PS - students' performance in stoichiometry problem solving

Table 2

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.897	0.805	0.803	1.003
2	0.917	0.841	0.836	0.914

*Predictors: Model 1 (Constant), PR
*Predictors: Model 2 (Constant), PR, C
*Dependent Variable: PS

Next, in Stepwise MRA, the results of the Analysis of Variance (ANOVA) would give us the 'overall fit' between the predictors and the criterion. The results (see Table 3), indicated that the overall strength of the relationship between the predictors and the criterion was statistically significant [$F(3,104) = 182.792$, $p = 0.000$, MSE = 0.835].

Table 3

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	458.110	3	152.703	182.792	0.000
Residual	86.881	104	0.835		
Total	544.991	107			

The results of the predictive strength of each predictor on the criterion are summarized in Table 4. PS was found to be significantly predicted by only two of the three predictors; C (Beta = .275, t = 4.853, p = .000), and PR (Beta = .697, t = 12.285, p = .000). Mathematical ability (MA) was excluded from the model since the analysis yielded an insignificant correlation to PS with the Beta value at 0.029. The results showed Beta values which indicated that PR is the strongest predictor of PS followed by C. The predicted equation for this model could be written as:

$$PS = -0.518 + 0.207C + 0.581PR$$

where:

PS - students' performance in stoichiometry problem solving
C - students' understanding of the mole concept

PR - students' problem representation ability

Table 4
Regression Coefficients, Confidence Intervals and Collinearity Statistics for the Predictors of Students' Performance in Stoichiometry Problem Solving

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std.Error	Beta			Tolerance	VIF
1 (Constant)	- 0.518	0.196		-2.649	0.009		
C	0.207	0.043	0.275	4.853	0.000	0.472	2.117
PR	0.581	0.047	0.697	12.285	0.000	0.472	2.117

*Statistically significant at $\alpha = .05$

The regression coefficient of each variable gives an account of the increase in the criterion if a particular independent variable increases by a unit when the other independent variables are held constant. For instance, one unit increase of PR would generate an increase of 0.581 unit of PS when C and MA are held constant.

Table 4 above also shows that the effects of multicollinearity on the analysis were not serious. The values of Tolerance and Variance Inflation Factors (VIF) suggested that the relationships among the predictors were not significant. This result were consistent with the literature which suggested that mathematical ability was not actually a 'popular' factor that would influence students' performance in stoichiometry problem solving. Only two studies suggested the worth of this factor (BouJaoude & Barakat, 2000; Wink et. al., 2000).

To get an alternative perspective on the MRA and in an attempt to get a clearer 'picture' and to determine whether mathematical ability (MA) could really be 'dropped' from the regression equation, individual relationships were then determined between:

(i) students' with adequate and inadequate understanding of the concept of mole (C) with their performance in solving stoichiometry problems,
(ii) students' with high and low problem representation ability (PR) with their performance in solving stoichiometry problems,
(iii) students' with high and low mathematical ability (MA) with their performance in solving stoichiometry problems,

Using the t-test to compare the performance of students in the stoichiometry test, produce some interesting results. All the results (Tables 5 to 10), were significant:

(i) Students with adequate understanding of the concept of mole (HIGHC) performed better (mean = 3.97) than those with inadequate understanding (LOWC) (mean = 0.67) in the stoichiometry problem solving test.
(ii) Students with high problem representation ability (HIGHPR) performed better (mean = 4.82) than those with lower ability (LOWPR) (mean = 0.73) in the stoichiometry problem solving test.
(iii) Students with high mathematical ability (HIGHMA) performed better (mean = 3.23) than those with lower mathematical ability (LOWMA) (mean = 0.48) in the stoichiometry problem solving test.

The regression results seemed to significantly support only the two variables (C and PR) but do not give a significant correlation with MA. The t-test results however, seemed to support that students' mathematical ability also has a significant positive correlation with their performance in stoichiometry problem solving.

Table 5
Group Statistics for C and PS

C	N	Mean of PS	Std. Deviation	Std. Error Mean
HIGHC	39	3.970	1.633	2.069
LOWC	69	0.666	1.653	1.198

Table 6
Independent Samples Test for PS between HIGHC and LOWC

	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal Variances Assumed	7.810	104.000	0.000	2.457	0.248

Table 7
Group Statistics for MA and PS

MA	N	Mean of PS	Std. Deviation	Std. Error Mean
HIGHMA	60	3.233	2.295	0.296
LOWMA	48	0.479	0.825	0.119

Table 8
Independent Samples Test for PS between HIGHMA and LOWMA

	t-test for Equality of Means				
	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal Variances Assumed	7.910	106.000	0.000	2.754	0.348

Table 9
Group Statistics for PR and PS

MA	N	Mean of PS	Std. Deviation	Std. Error Mean
HIGHPR	38	4.820	1.346	0.296
LOWPR	80	0.730	0.976	0.119

Table 10
Independent Samples Test for PS between HIGHPR and LOWPR

	t-test for Equality of Means				
	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal Variances Assumed	7.902	109.000	0.000	2.198	0.218

The Multiple Regression analysis seemed to indicate that mathematical ability is not a worthy variable to be included in the regression, and the t-test is not a ‘strong’ indicator that could be used to support the initial regression model, the second model of the regression which only includes the two predictors from the first MR analysis were retained . Therefore, the regression model would be maintained:

$PS = -0.518 + 0.207C + 0.581PR$, where:

PS - students' performance in stoichiometry problem solving
C - students' understanding of the concept of mole
PR - students' problem representation ability

Qualitative Analysis of Interviews

A. Analysis of Teachers' Perceptions

The respondents of the interview were three senior teachers with more than 9 years of teaching experiences and 2 novice teachers with less than 2 years experiences. The analysis is summarized as below:

1. Importance of the understanding on the topic of stoichiometry for chemistry students

Two teachers (Teacher 3 and 4) admitted that they had underemphasized the stoichiometric topic in their teaching. Their teaching of the topic rarely probed students understanding of the underlying chemical concepts that is prerequisite in order for the students to solve stoichiometric problems very well. "*Maybe I'm partly responsible for that, I didn't really emphasize the topic when I was teaching. I simply breezed through the topic as I thought that the topic is quite easy*" (Teacher 3).

One interesting observation is the novice teachers (Teacher 2 and 5) seemed to be more interested in probing students' understanding in the topic. This is quite understandable since these novice teachers had just graduated from their training colleges and still have the drive to practice what they had just learned. Senior teachers (Teacher 1, 2 and 4) appeared to be more concerned with finishing the syllabus as soon as possible, so that they would have ample time to do a lot of drilling to prepare students for their examinations. With only four periods a week (approximately 140 minutes per week), teachers find themselves pressured to cover all the content of the subject as quickly as possible. Some extra periods are geared towards doing more practice and exercises with the aim of maintaining the school's performance in the SPM examination. Most senior teachers (teacher 1 and 4) seemed to be very complacent in their 'comfort zone' and think that their expertise in the subject is already adequate to build a solid understanding of the subject.

2. Teachers' difficulties in teaching the stoichiometry topic

Another interesting finding from this interview is that a greater number of teachers (Teacher 1, 2 and 4) do not perceive that teaching the stoichiometry topic to their students as a hard thing to do. Teachers were literally confused as to why students did not do well in solving stoichiometry problems. They posited that maybe their negligence to highlight the importance of the topic to their chemistry students, may contribute partly to their students performance in stoichiometry problem solving. Teacher 1, 2 and 4 however, claimed that the topic was 'easy' to teach and all teachers interviewed engaged the algorithmic approach to the topic by introducing the M_aV_a/M_bV_b = a/b formula right from the beginning of the lesson of the topic. This feeling might stem from the fact that Teacher 1 and 2 came from schools with selected or better ability students. Thus, they perceived that teaching the stoichiometry was 'easy'.

On the other hand, Teachers 3 and 5 did not feel that it was an easy thing to teach the topic to students. They asserted that there were a lot of things to be taken into consideration before students can attempt to solve the problems. They also believe that they should prepare students with adequate understanding of the concept of mole, the knowledge of writing the correct chemical formula and balancing the chemical equation, before giving the students stoichiometry problems.

3. How teachers normally introduce the topic

Senior teachers did not bother with introductions. They normally start their lesson on the topic with an example of an easy stoichiometry problem. They would show all the necessary steps to solve the problem and give the students a few examples. Later, the teachers would increase the degree of difficulties of the problems and discuss the answers with the students. Senior teachers seemed to prefer the algorithmic approach to introduce the topic due to the very limited time allocated to chemistry in the school time-table.

Novice teachers prefer to 'play around' first with the calculations on mole, writing chemical formula and balancing chemical equations, before introducing the topic to their students. Then only they would give examples on the stoichiometry problems and ways to solve them. Nevertheless, novice teachers also seemed to share the same opinion with the senior teachers that the algorithmic approach was perhaps the easiest way to teach the topic.

4. Major difficulties faced by students when solving stoichiometry problems

Three teachers (Teachers 1, 4 and 5) hinted that students did not seem to understand the significance of the coefficients in a chemical equation. "*Many students just apply the trial and error approach, they would try different sets of numbers, use the formula until the answer seems right*" (Teacher 1). "*They do not know the importance of the coefficients in the chemical equation given in the question; many do not even know how to balance a chemical equation*" (Teacher 4). "*Some students do not understand the values of a and b in the formula*" (Teacher 5). Teacher 4 also seemed to think that a lot of students cannot determine the 'limiting reagent' in a given problem, when one substance is added in excess. "*Some students seemed to think that the reagent with the lowest coefficients in the chemical equation is the limiting reagent. However, they could not explained it when there are more than one reagent have the same lowest coefficient value*". This problem is related to the significance of the coefficients in a chemical reaction.

Other teachers (Teachers 1, 2 and 3) observed that students might be confused or did not know the definitions of and relationships between stoichiometric entities in general. Misunderstanding or inadequate understanding of the concepts that sounds phonetically similar such as mole, molecule, molarity, molar mass, etc, seemed to hamper students' performance in stoichiometry problem solving. "*They sound almost the same, mole, molecule, molarity….no wonder students are so confused*" (teacher 2). These similarly sounded chemical concepts were all introduced to chemistry students at the beginning of the Form Four year. Even though teachers were aware of the significance of students' understanding of these concepts, due to the time constraints, teachers normally just rushed through them in their chemistry lessons.

The particulate nature of chemistry may also make it confusing for students to determine the mole of substances. To calculate the mole of a substance in atomic state is quite different from a substance of molecular state. "…*to calculate the mole of sulphuric acid, they need to use the volume and molarity of the acid, but to calculate the mole of copper(II) oxide used, they must divide the mass by the molar mass of the substance….students do not understand this"* (teacher 1). This misunderstanding may arise from students' inability to comprehend that chemicals in different physical state may also be different in their particulate nature. Students may find it difficult to understand that substances may exist in atoms, molecules and ions. This problem could be minimized if teachers presented the lessons in a more concrete approach. Instead of using the 'chalk and talk' method, which is sometimes very confusing to the students, teachers may use the 3-D illustration of the concepts. The lack of teachers' initiative to allocate more time in providing this solid grid of understanding the chemical concepts may result in more misunderstandings or misconceptions.

In short, teachers seemed to think that determining the correct mole ratio of reactants and products, and calculating the mole of the respective chemical substances are the two major difficulties faced by students when solving the problems.

5. Factors that might contribute to students' success in solving stoichiometry problems

All teachers conceded that students' ability of problem representation is a very important factor that influences students' performance in stoichiometric problem solving. The first step a student would have to take is to translate the worded problem into a balanced chemical equation, and then transferring all information given in the question into a suitable mathematical equation. If a student failed to do this, he/she would not be able to proceed. "…*students must be able to write the correct mathematical equation from the original question given*" (Teacher 1). "*If they could not identify the correct values of molarity, volume or mass of the substances, they may not be able to calculate and use the formula correctly.*" (Teacher 2) Besides representing the worded problem into a mathematical equation, they must also understand what each symbol in the equation means; otherwise they would plug in the wrong numbers into the symbols. In the $M_aV_a/M_bV_b = a/b$ formula, the M symbol is sometimes mistakenly understood as the mole or the mass of substances. Students must be able to determine the correct values of molarity, volume, mass, etc., from the question and also use them in the correct units. In stoichiometry problem solving, using the correct units for the different entities is crucial. For instance, students must be aware if the concentration of solutions given in the question is based in gdm^{-3} or $moldm^{-3}$. If the concentration is given in gdm^{-3}, then they must first convert it into $moldm^{-3}$ before using the $M_aV_a/M_bV_b = a/b$ formula.

6. The effect of students' understanding of the concept of mole on their performance in stoichiometry problem solving

Most teachers agreed that students need to be well versed with the particulate nature of substance in order to be able to calculate the respective entities. Strangely however, some teachers (Teachers 3, 4 and 5) did not perceive that the understanding of the mole concept particularly, is essential for the students to solve stoichiometry problems successfully. Teacher 5 says; "*…no, I just don't think that a student needs to understand the mole concept very well in order to solve it, they must know the mole concept in order to be able to know how to apply the formula, that's it*". This teacher seemed to give contradictory answers to the question. Initially she pointed out that it is important for students to have an adequate understanding of the concept of mole in order to solve the problem, however when pressed further, she seemed unsure of herself. This uncertainty may be caused by the teacher's inadequate understanding of the concept. Even though the researcher did not ask the teachers to explain the concept of mole in this interview, it could be discerned that some teachers could also had some misunderstandings of the concept. It would be so disappointing if teachers themselves perceive the concept of mole only as the written definition of the concept, without really understanding what it really means.

7. The effect of students' mathematical ability on their performance in stoichiometry problem solving

Teachers, however, have some disagreement on whether mathematical ability of the students would greatly influence their performance in stoichiometry problem solving. Two teachers (Teachers 1 and 4) seemed to perceive that a sound mathematical ability of the students would help them a lot in solving the stoichiometry problems. Yet, the other three teachers (teacher 2, 3 and 5) do not seem to agree with this. They viewed that even students with minimal mathematical ability would be able to solve the problems if they had a sound understanding of mole ratio of reactants and products, and an adequate ability to translate the worded problems into correct mathematical equations.

In short, comparing the views given by these teachers revealed some differences in their pedagogical approach in teaching the topic. The senior teachers seemed to rely heavily on the algorithmic approach in her teaching. On the other hand, young teachers seemed more concerned about students' understanding and ability to use the correct mole formula in solving the problems. All teachers asserted that students' representation ability and the ability to use the correct mole ratio are the major factors that would determine students' success in stoichiometry problem solving. However, they also believed that students' conceptual understanding on the concept of mole and mathematical ability are not the important factors that would influence their performance in solving the problems.

B. Analysis of Students' perceptions

Ten students were randomly picked out from all the five classes of respondents that responded to the stoichiometry test earlier. The students were requested to answer 6 written subjective interview questions about stoichiometry problem solving. The analysis is summarized as follows:

1. Importance of the stoichiometry topic to chemistry students

Most students seemed to be aware of the importance of the topic but they could not quite put their finger on the reason. Some smart students (student 1, 2, 3 and 10) posited that the topic is very important because 'it links with the other topics in chemistry, and it involves a lot of calculations'. They seemed to be rather vague about the importance of the topic.

2. Students' views on the difficulty of the topic of stoichiometry

Many of them do not consider that stoichiometry is a difficult topic to understand (student 1, 2, 3, 8, 9 and 10). They seemed to give an impression that it is an easy topic to learn. Some (student 1, 2 and 3) perceive the topic is just a matter of plugging in the correct numbers into the formula. This could be explained from the students' view that solving the problems only involves simple calculations.

3. Students' major difficulties in learning the topic

The terms 'mole' and 'molecule' are the most common misunderstood terms in this study. This misunderstanding seemed to stem from the lack of students' understanding that particles may exist in the forms of atoms, molecules or ions. Almost half of the number of students seemed unaware that the difference between 'mole' and 'molecule' (students 6, 7, 8 and 9). The close resemblance in the phonetic pronunciation and spelling of the two words seemed to trigger the confusion. In fact some students thought that the two terms are identical, have the same meaning and can be used interchangeably, “1 mole contains 1 molecule” (students 2 and 9).

Since quite a lot of new terms are being introduced all at once, within the topic of stoichiometry, which often sound similar to each other or include related concepts (e.g. the ‘mole’, ‘molecule’, ‘molar mass’, ‘amount of substance’, ‘number of particles’, etc.), beginners in stoichiometry should be given a chance to review these definitions while practicing stoichiometric problems. This seems also appropriate because many misconceptions are likely to arise when definitions and connections of these terms and concepts are misunderstood.

4. Students’ views on the factors that contribute to students’ success in solving the problems

When asked about factors that would contribute to their success in solving stoichiometry problems, some students (student 1 and 5) seemed to agree that translating a worded problem into an appropriate mathematical equation would determine the success of the exercise. Student 1, 2 and 10 said that it is also important they start with a balanced chemical equation. However, their problem solving exercise showed that only student 2 tried to balance the equation first. Student 1 and 10 might be so careless in their haste to finish the questions as quickly as possible, that they did not balance the equation first. Interestingly, two students (student 3 and 10) pointed out that getting the correct ‘mole fractions’ of the reactants and products are also crucial to solve the problem, so that they could plug in the correct numbers into the formula.

In short, students implied that the ability to balance the chemical equation, to determine the correct mole ratio and the ability to translate a worded problem into a correct mathematical are the three important factors that contribute to their success in solving the problems.

5. Students’ views on the influence of their understanding of the concept of mole on their performance in stoichiometry problem solving

More than half of the number of students (student 1, 2, 5, 6, 8 and 10) agreed that the understanding of the concept of mole influences their performance in solving the problems. However, most of them were more concerned in using the correct formula to calculate the mole of substances. The students could not explain that a sound understanding of the concept of mole would help them to determine the appropriate formula to use in calculating the mole. The weaker students seemed comfortable with just memorizing all the possible mole formula to help them in solving the problems. Nevertheless, due to their lack of understanding of the mole concept, they sometimes used the wrong formula. This particular finding has made the researcher realized that a teacher should made it clear to her/his students that the understanding of the concept of mole is not just useful to answer theoretical questions, but also would be crucial when engaging the correct formula in stoichiometry or any other chemistry calculations.

6. Students’ views on the influence of mathematical ability on their performance in stoichiometry problem solving

Almost all students (all students except student 4 and 7) seemed to think that mathematical ability influences their ability to solve the problems. However, they indicated that only minimal mathematical ability is needed to solve the problems. Since solving stoichiometry problems do not require one to solve ‘calculus’ problems, they viewed that even with low mathematical ability, they would be able to solve the ‘simple’ calculations.

Conclusion

The MRA showed that students’ problem representation ability is the most dominant factor that would influence their success in stoichiometry problem solving. The model suggests that students’ problem representation ability and their understanding of the concept of mole are the two major determinants of students’ performance in stoichiometry problem solving. In other words, students need to be able to have the conceptual understanding of the problem, namely, being able to translate the worded problems into a suitable chemical and mathematical equation, and using the correct formula to calculate the mole, before they can solve the problem.

The qualitative analysis of the interview supports the statistical analysis of the test. This indicates teachers should be aware that many students have some difficulties in ‘making sense’ of the chemical reaction itself. This contributes to the students’ difficulties in translating the worded problem into a suitable mathematical equation. To conclude, in the teaching and learning sessions in the classroom, teachers should not practice the ‘short cut’ approach (algorithmic methods) in the entirety. Students ought to be exposed and guided to understand the mole concept very well. Teachers need to make the effort to make sure they could grasp the underlying conceptual foundation of stoichiometry before introducing the algorithmic way of solving the problems.

References

Ashmore, A. D., Frazer, M. J., & Casey, R. J. (1979). Problem solving and problem solving network in Chemistry. *Chemistry Education. 56*(6), 377-379.

Bodner, G. M., & McMillen, T. L. B. (1986). Cognitive restructuring as an early stage in problem solving. Journal of Research in Science Teaching, 23(8), 727 – 737.

BouJoude, S., & Barakat, H. (2000). Student problem solving strategies in stoichiometry and their relationships to conceptual understanding and learning approaches. Journal of Science Education, 7(3), 42 – 81.

Bunce, D. M., & Heikkinen, H., (1986). The effects of an explicit problem-solving approach on mathematical chemistry achievement. Journal of Research in Science Teaching, 23, 11-20.

Case, J. M., & Fraser, D. M. (1999). An investigation into chemical engineering students' understanding of the mole and the use of concrete activities to promote conceptual change. International Journal of Science Education, 21(12), 1237 – 1249. ERIC Accession No: EJ 596034. Retrieved June, 12, 2005. URL: http://www.chemeng.uct.ac.za/home/jcase/CaseFraserIJSE1999.pdf

Chi, M. T. H., & Bassock, M. (1991). Learning from examples vs. self explanations. In Resnick, L. S. (ed.). Knowing, learning and instruction: Essays in honor of Robert Glaser (pp 251 – 282). Hillsdale, NJ: Lawrence Erlbaum Associates.

Chiu, M. H. (2001). Algorithmic problem solving and conceptual understanding of chemistry by student at a local high school in Taiwan. *Proceedings of the National Science Concept*, 11(1), 20-38.

Dahsah, C. & Coll, R. K. (2007). Thai grade 10 and 11 students' conceptual understanding and problem-solving ability in stoichiometry. *Research in Science and Technology Education*, 25, 227-241.

Davidowitz,B, Chittleborough, G & Murray, E. (2010). Student-generated submicro diagrams: a useful tool for teaching and learning chemical equations and stoichiometry. Chemical Education Research and Practice**,** 11**,** 154-164.

Frazer, M. J. & Servant, D. (1987). Aspects of stoichiometry titration calculation. *Education in Chemistry*, 23, 54-56.

Gabel, D. L., & Sherwood, R. D. (1984). Analysing difficulties with mole-concepts tasks by using familiar analog tasks. Journal of Research in Science Teaching, 21(8), 843 – 851.

Gauchon, L., & Méheut, M. (2007) Learning about stoichiometry: from students' preconceptions to the concept of limiting reactant. Chemical Education Research and Practice**,** 8**,** 362-375.

Hanson, D., & Wolfskill, T. (1998). Improving teaching and learning process in general chemistry. Journal of Chemical Education, 75(2), 143 – 148.

Heyworth, M. (1999). Procedural and conceptual knowledge of expert and novice students for the solving of a basic problem in chemistry. *International Journal of Science Education*, 21(2), 195-211.

Huddle, P. A., & Pillay, A. E. (1996). An in-depth study of misconceptions in stoichiometry and chemical equilibrium at a South African university. Journal of Research in Science Teaching, 33(1), 65 – 77.

Ibrahim M. D. (2011). Methods used by pre-service Nigeria Certificate in Education teachers in solving quantitative problems in chemistry. Chemistry Education Research and Practice, 12, 427 – 433.

Jonassen, D. (2003). Using cognitive tools to represent problems. Journal of Research on Technology in Education, 35(3), 362 – 378.

Krieger, C. R. (1997). Stoogiometry: A cognitive approach to teaching stoichiometry. Journal of Chemical Education, 74(3), 306 – 310.

Lythcott, J. (1990). Problem solving and requisite knowledge of chemistry. *Journal of Chemical Education*, 63(3), 248-252.

Meor Ibrahim Kamaruddin, Marie Stella Ambrose, & Ling, H. L. (2003). *Penguasaan isitilah kimia dan hubunganya dengan penyelesaian masalah konsep mol: Satu kajian kes di kalangan pelajar tahun dua jurusan pendidikan kimia di falkuti pendidikan*. Universiti Teknologi Malaysia. Retrieved from http://eprints.utm.my/2338/112.Meor.pdf

Musa, U. (2009). Teaching the mole concept using a conceptual change method at college level. Education, 129(4), 683 – 691.

Niaz, M., & Lawson, A. E. (1985). Balancing chemical equations: The role of developmental level and mental capacity. Journal of Research in Science Teaching, 22(1), 41 – 51.

Noraihan Ismail (2008). *Masalah konsep mol dalam konteks penyelesaian masalah di kalangan pelajar tingkatan empat* (Tesis Sarjana Muda yang tidak diterbitkan). Universiti Teknologi Malaysia, Skudai.

O. Daley, H. Jr., & O.Malley, R. F. (1988). Problems in chemistry (2^{nd}. Edition). New York: Marcel Dekker, Inc.

Patton, M. Q. (2001). Qualitative evaluation and research methods (3^{rd}. ed.). Thousand Oaks, CA: Sage Publications, Inc.

Ploetzner, R., & Spada, H. (1998). Constructing quantitative problem representations on the basis of qualitative reasoning. Interactive Learning Environments, 5, 95 – 107.

Poole, R. L. (1989). Teaching stoichiometry: A two-cycle approach. Journal of Chemical Education, 66(1), 57 – 58.

Schmidt, H. J. (1990). Secondary school students' strategies in stoichiometry. *International Journal of Science Education*, 12, 457-471.

Schmidt, H. J. (1992, March, 23). Stoichiometric problem solving in high school chemistry. Paper presented at Annual Meeting of the National Association for Research in Science Teaching, Boston, Germany.

Schmidt, H. J. & Jignéus, C. (2003). Students´ Strategies In Solving Algorithmic Stoichiometry Problems. Chemical Education Research and Practice**,** 4, 305-317.

Schwartz, S. H. (1971). Modes of representation and problem solving: Well evolved is half evolved. Journal of Experimental Psychology, 91, 347 -350.

Staver, J. K., & Jacks, T. (1988). The influence of cognitive reasoning level, cognitive restructuring ability, disembedding ability, working memory capacity and prior knowledge on students' performance on balancing equations by inspection. Journal of Research in Science Teaching, 25(9), 763 – 775.

Stevens, J. (1996). Applied multivariate statistics for the social sciences. Hillsdale, NJ: Lawrence Earlbaum.

Wagner, E. P. (2001). A study comparing the efficacy of a mole ratio flow chart to dimensional analysis for teaching reaction stoichiometry. Journal of School Science and Mathematics, 101(1), 10 – 22.

Wink, D. J., Gislason, S. F., McNicholas, S. D., Zusman, B. J., & Mebane, R. C. (2000). The MATCH program: A preparatory chemistry and intermediate algebra curriculum. Journal of Chemical Education, 77(8), 999-1001.

Yarroch, W. L. (1985). Student understanding of chemical equation balancing. Journal of Research in Science Teaching, 22, 449-459.