# How a Form Four Student Solved the Mole Concept Objective Problems

by

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## 1.0 Background of the study

Chemistry is one of the science subjects offered to pure science classes in our upper secondary schools in Malaysia. The sixth challenge in Vision 2020 stated that Malaysia would move forward to become a country that not only used science and technology but also as a leader in the field of science and technology. Malaysia also aimed to become a country that was ahead of other countries in science and technology. Thus it is important and necessary to possess a workforce that is proficient in science and technology. With that our Ministry of Education has targeted to attain a ratio of 60:40 between science and art students in the upper secondary schools and also in higher institutions by the year 2000.

In order to achieve the said ratio, it is important for our students to have a strong foundation in science and mathematics. According to Shohtoku (1993), 'a student who possesses a strong foundation in science and mathematics has a higher opportunity to pursue his/her study in the related field in higher institutions later'. Therefore a strong foundation in science subjects at an early stage is important, and form four can be regarded as a critical stage whereby for the first time the students were exposed to the three pure sciences. Teachers do play a very important role in helping the students to attain a strong foundation in pure science subjects.

## 2.0 Problem statement

In the *Sijil Pelajaran Malaysia* (SPM) chemistry syllabus, students are exposed to a number of important chemistry concepts such as mole concept, reaction stoichiometry, oxidation-reduction, acid and base, electrochemistry and others. According to Huddle and Pillay (1996), the mole concept, reaction stoichiometry and oxidation-reduction were among the four topics that learners found to be most difficult and highly abstract. As a chemistry teacher in schools, I always regard mole concept as the heart of chemistry because it is the prerequisite knowledge for other concepts. According to Sulaiman N.Razali & Yager (1994) "mole is the important foundation for more complex chemical concepts such as stoichiometry, concentration and, equilibrium constant.' In fact mole concept resurfaces in most of the topics

followed in the SPM chemistry syllabus. This seems to suggest that it is important for one to grasp the mole concept if one intends to do well in chemistry.

As chemistry teacher I used to encounter problems like students found it difficult to grasp the mole concept especially when it was just introduced. From my observations, usually these students also encountered problems in additional mathematics which I happened to teach also.

Yet surprisingly, I observed that some of these students managed to grasp the mole concept later when they were in Form Five and some would just remain 'shaky' in the sense that they could solve some of the mole concept problems. I kept wondering why some of the students suddenly became 'clever' and was able to grasp the mole concept when they reached Form Five. Why the same students just could not see 'eye-to-eye' with me in the first place when they first learned mole concept. I used to relate the incident with the facts that the students might have not possess certain thinking skills when they were in Form Four which they could have acquire later when they were older, that might be able to explain why they could not think like I think.

## 3.0 Objective of study

This study was designed to find out how 6 (two each from the high, average and below average achiever groups) Form Four students solved the mole concept objective questions. I chose problem solving because it was usually used as a tool to measure progress and achievement of students. When a student could solve problems, it implied that he/she had the ability to apply what he/she had learned.

While solving the mole concept problems, most probably the subjects would engage different types of thinking skills and also recalling relevant knowledge from the memory. Apart from the thinking skills and the knowledge, I was interested to look into the strategies used by the subjects while solving the problems. Most likely the subjects would encounter some difficulties in solving the problems, thus I would pay some attention to the difficulties faced and if possible to find out the reasons why those difficulties arose.

In order to address the objectives of the study, this study was designed to answer the following research questions, that is:

(i) What types of thinking skills did the subjects engage when they solved the mole concept objective questions?
(ii) What types of knowledge and strategies did the subjects use when they solved the mole concept questions?
(iii) What were the difficulties faced by the subjects when they solved the mole concept questions?

## 4.0 Research methodology

A set of nineteen objective questions was used as the problems. These nineteen questions were taken from the past year questions in the *Sijil Pelajaran Malaysia* (SPM) examination, from the year 1994 to 2001, and also from the SPM chemistry reference books.

The questions consisted of sixteen questions with four options given as A, B, C and D where only one of the options was correct. The remaining three were questions consisted of options I, II, III and IV where one or more of the options could be correct. These were the typical types of objective questions asked in the SPM examination. The nineteen questions were finally chosen because they evaluated various aspects of mole concept and were not redundant. These questions were given to an experience chemistry lecturer for a second opinion.

The problems were given to the subjects to solve. Their chemistry teacher nominated all the subjects. While the subject was solving the problems, she (all the six subjects were girls) was asked to write down all the steps even though the questions consisted of objective questions, at the same time, she was asked to verbalize or talk-aloud (think-aloud), that is to say out all her thinking while solving the problems. The verbal reports were recorded using a cassette tape recorder and the problem solving session was also recorded using a video camera. I took note of relevant observations during the recording sessions. After the recording sessions, I tried to go through some of the questions with the subjects, making clarification and explanation where necessary.

After the recording sessions, the verbal report was transcribed. The lines in the transcript were numbered for reference purposes. The steps in the written work were listed out. The transcript served as a very important data to find in the unwritten steps and explanation. The transcript was further analyzed to identify thinking skills engaged and strategies used by the subject.

However, it was realized that the data obtained were still not rich enough because the clarification and explanation given during the recording sessions were rather superficial. With that a second recording session was done on Jenny (not her real name) who happened to be able to articulate well, and also due to the time constraint, only Jenny's data was analyzed for knowledge, thinking skills, strategies used and difficulties encountered by Jenny.

## 5.0 Summary of Findings

Among the different types of data obtained, the written work served as a backbone data as it provided a structure for other data to attach. The verbal report filled in the empty spaces for those data not written. The combined data from the

written work with that of the verbal reports gave a very clear picture on the thinking sequence took place. On the other hand, the video recording was useful for giving information when Jenny remained quiet or when she paused. Together with my observations and information collected from the conversation before the recording session, and the clarification after the recording session, the data were triangulated and analyzed.

## 5.1 Knowledge

The findings indicated Jenny required more than mole concept to solve the problems. A good knowledge in mathematics was a great advantage. Jenny had to do a lot of calculation involving the conversion of mass, number of particles and volume into mole by applying mole formula as below:

$$\text{Mole} = \frac{\text{mass}}{\text{atomic/molecular/formula mass}};$$

$$\text{Mole} = \frac{\text{volume}}{\text{molar gas volume}(24\text{dm}^3 \text{ or } 22.4\text{dm}^3)};$$

$$\text{Mole} = \frac{\text{number of particles(molecules/ions/atoms)}}{\text{Avogadro's Constant}}$$

Jenny had to convert unit such as $cm^3$ into $dm^3$ and vice versa in two of the questions involving gas volume. Jenny was extremely good in this type of conversion that she did it all mentally without using a calculator. Other than that Jenny had to do simple calculation involving addition, subtraction, multiplication and division. Other relevant knowledge that Jenny needed to have in order to solve the problems were summarized as below:

(i) Chemical symbol/formula, empirical/molecular formula
Jenny had to be able to interpret a chemical formula into the ratio between different elements in a chemical formula and vice versa.

(ii) Formulation of a linear equation for unknown such as mole, atomic mass and substance mass
For example: $\frac{5.6}{x} = 0.1\text{mol}, \therefore x = 56$ (relative atomic mass)

(iii) Conversion of unit from $cm^3$ to $dm^3$ and vice versa
Jenny could change 0.24 $dm^3$ into 240 $cm^3$ and vice versa

(iv) Charges on ions

It would be a great help if Jenny could memorize the charges of lead, iron, zinc and chloride ions, so that she could form the formula for the compounds formed between the metal elements and chloride.

(v) Molecular/ formula mass calculation from the atomic masses provided
Calculating the mass of substances, after getting the formula of the substances, Jenny calculated the mass for the substances by referring to the relative atomic masses given.

(vi) Ratio/ proportional calculation
Calculation involving chemical equation usually involved ratio or proportion.

(vii) Chemical equation
Jenny was required to extract information from a chemical equation given.

## 5.2 Thinking skills

It was found that Jenny engaged the following thinking skills while she solved mole concept objective problems:

(i) Analyzing – analyzing the questions
(ii) Applying formula – apply mole formulas
(iii) Associating – forming a connection between things
(iv) Assuming – assuming mole value is directly proportional to gas volume and also quantity of particles
(v) Calculating/Calculating mentally/Calculating proportionally – simple calculation such as addition, subtraction, multiplication, division. Converting unit, from $dm^3$ to $cm^3$ and vice versa without using calculator. Calculating proportionally when involving formulation linear equations for unknown and solved for it. Calculation involving chemical equations usually involved proportional/ratio calculation.
(vi) Categorizing – categorizing calculation according to elements especially when finding empirical formula or molecular formula.
(vii) Confirming – confirm the answer by comparing it with options given.
(viii) Comparing – comparing the answer obtained with the options. Comparing the ratio and etc.
(ix) Conjecturing – deciding something is true or likely based on the information obtained
(x) Deducing – to know something as a result of considering the information or evidence obtained
(xi) Disconfirming – rejecting an answer
(xii) Estimating – making a guess or making a rough calculation
(xiii) Focusing – paying particular attention to things
(xiv) Extracting important information- listing important information
(xv) Formulating equation – construct an linear equation and solve
(xvi) Identifying errors – spotting errors and mistakes
(xvii) Recalling – recalling knowledge from the memory

(xviii) Recognizing – able to recognize important terminologies, information and terms in the questions
(xix) Referring to relevant information – referred to the information provided especially the relative atomic masses given at the end of the questions
(xx) Relating – relating items to each other
(xxi) Searching for relevant information – while reading the questions at the same time, Jenny was searching for relevant information
(xxii) Symbolic representing- Jenny used x to represent unknown, chemical symbols to represent compounds/ substances

## 5.3 Strategies

Jenny demonstrated a few strategies where two of them were her insight upon certain concepts after a lot of practices and exercises she had gone through. Altogether eleven strategies were identified as listed below:

(i)

$$Bil\ mol = \frac{\square}{JAR \text{ (relative atomic mass)}}$$

*or Isipadu* (volume)

*or Pemalar Avogadro* (Avogadro's Constant)

Jenny summarizes the three mole formulas into one. She drew a box for the denominator which according to her was changeable. The numerator could either be *JAR (jisim atom relatif)* (it should be JA), *isipadu* (volume) or *Pemalar Avogadro* (Avogadro's Constant) depended on the nature of the denominator. If it were mass then the numerator would be relative atomic mass. The correct one would be either atomic/molecular/formula mass. On the other hand, if the denominator was a gas, then the numerator got to be molar volume of either 22.4 $dm^3$ (at standard temperature and pressure) or 24 $dm^3$ (at room temperature and pressure) depended on the conditions given. However if quantity of matter was given in atoms, molecules or ions, then it was necessary to use the third formula which involved Avogadro's Constant.
Jenny claimed that she came out with this formula on her own after solving a lot of mole concept problems. She even shared with her friends this formula because she felt that this formula was easy to remember.

(ii) Jenny converted gas volume from $cm^3$ into $dm^3$ and vice versa mentally without using a calculator or writing any steps. Jenny explained that she acquired the said ability after doing a lot 'change' since primary school and also in physics. Given 0.24 $dm^3$, Jenny immediately wrote down 240 $cm^3$ , also when given she changed 120 $cm^3$ into 0.12 $dm^3$.

(iii) Jenny calculated $\frac{3\times10^{21}}{6\times10^{23}}$ mentally without using a calculator. First she divided 3 with 6 and she got 0.5. Then she settled the indices by subtracting 23 by 21 and she got –2. So the answer was then 0.5 x $10^{-2}$. Immediately she transformed it into 5 x $10^{-3}$ mentally.

(iv) Jenny was asked to find the molecular formula for an organic compound. She calculated the empirical formula and she obtained $C_6H_{12}O$. The molecular mass of the compound was given as 200g. In order to find the molecular formula Jenny divided 200g by the mass calculated from the empirical formula and the answer was 2, that is the molecular mass was twice heavier than the mass of the empirical mass. From there Jenny doubled the ratio of the elements in the compound $C_6H_{12}O$ and she got the right answer $C_{12}H_{24}O_2$.

(v) This strategy was a timesaving strategy. Jenny got stuck when she read option I in one of the question. She left it and said that she would return later. She went back to option I after she had read through all the other three options, II, III and IV. This was a smart approach as the combination of the options might help her to confirm her choices.

(vi) In one occasion Jenny was asked to find the option which contained the biggest gas volume. Instead she calculated the mole values for the options one by one and not the volume. She equaled the option which contained the biggest mole value to be the option contained the biggest volume too. Again she saved time. She did the same for another question where she equaled the biggest the mole value to be the option which contained the largest amount of particles.

(vii) Jenny seemed to have a preference in using x to represent a few unknowns within the same question. For example, in question 1, she used x to represent:

(a) The unknown element
(b) The mole value of element X
(c) The relative atomic mass of element X

Jenny did not got confused with three unknowns.

(viii) Jenny demonstrated a general pattern in approaching the problems. She would read the question first, as she read she would repeat key words/ phrases/figures/important information. To highlight them she chose to underline, draw boxes or circle them. After she was certain of what to do, she would proceed to the calculation. It was observed that Jenny hardly had any problem in solving the problems, as she just knew which formula to use without showing any hesitation. After she had work out the answer, she would conjecture it by comparing it with options provided. If the answer did not tally, she would quickly check her steps to identify the errors. Sometimes, she preferred to redo everything if the steps were messy. She would trial and error until she got the correct answer.

## 5.4 Difficulties

For the first problem solving session, Jenny got 15 questions correct. In the second session, Jenny got 18 questions out of 19 correct. However, she did not succeed in getting the correct answer for all the questions at her first attempt. She did encounter some difficulties while answering the questions. In a few occasions she had to trial and error two or three times before she obtained the correct answer. When the first answer she got did not tally with the options given, she would go back to her steps to spot her mistakes. She would keep on trying until she got the correct answer.

It was observed that the main difficulty faced by Jenny were as followed:

(a) There was insufficient information provided in the questions. For instance, she was asked to choose the ion which required the most number of chlorine. The options were given in a neutral form that is lead, zinc, iron and carbon, without any charges given. Jenny really had a hard time to recall charges of lead, zinc, carbon and iron. She encountered the said problem in both problem solving sessions.

(b) Another thing that gave Jenny big problem was the ambiguous terms used in such as 2.0 g hydrogen. Jenny had a hard time to figure out if this hydrogen was a gas or an element, thus resulted in her making irrelevant conclusion.

## 6.0 Suggestions

This study actually involved six subjects with two each chosen from the so-called high achiever, average achiever and low achiever groups. However, the data obtained especially from lower achiever group were not as rich as that obtained from Jenny, who was from the higher achiever group. And also due to time constraint, only data from Jenny was analyzed.

It was indeed necessary that the subject should be given some training on thinking-aloud. During the training, a similar problem was given to the subjects to try

and they were asked to verbalize as they solved the problems. The verbal report was recorded, transcribed and analyzed. A feedback was then given to the subjects so that they could improve and made necessary adjustment for the actual recording sessions in terms of the thinking-aloud.

However, for those subjects who were weak in chemistry, other methods might be more suitable. Some of the subjects tended to keep quiet and paused a lot. It was possible that the subjects had difficulty in the language and vocabulary, and also they might not have the relevant knowledge to go about solving the problems. A diagnostic study might be useful.

Future study could be done on other concepts in chemistry and also other science subjects like biology and physics. Apart from using objective questions, other types of problems like essay and structure questions could be used too.

## 7.0 Conclusion

As the finding was based on one subject only therefore there was no intention to make any generalization. Though it was indicative, it could shed some light on how a Form Four science student solved the mole concept problems. From the knowledge and the thinking skills engaged, it was clear that Jenny needed a lot of other knowledge together with the mole concept in order to solve the problems well. At the same time a strong mathematics background was a great advantage.

Together with the mole concept itself, Jenny needed to have other related knowledge while solving the problems. 24 thinking skills and eight strategies were discussed in this report. Jenny also encountered difficulties due to the fact that the questions did not provided sufficient information and used ambiguous terms that prevented Jenny from getting the right answer at the first attempt. However, she managed to get eighteen questions out of nineteen questions correct. The effect of previous problem solving session was positive.

Finally, I have to say, “Students do not really think like I think!”