Enhancing Conceptual Understanding in Science Instruction

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ENHANCING CONCEPTUAL UNDERSTANDING IN SCIENCE INSTRUCTION *

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Introduction

In the process of teaching science, our main concern is whether our students possess conceptual understanding after the instruction. It is well believed that students will generally have difficulties in learning science concepts, if they have alternative ideas in science, which have not been taken into consideration in the design of instruction. A large body of research studies has also shown that such alternative ideas (or misconceptions) are held stubbornly and difficult to be changed[1,2]. As a result, failing to identify and assess students' conceptual understanding will lead to ineffective instructional design. In some cases, identifying and assessing students' conceptual understanding is not a simple task, because traditional ways of assessment, such as solving quantitative problems by plug-and-chug, fail to function well due to the nature of the science concepts: generally, scientific concepts encompass many aspects, which, at times, cannot be satisfactorily described just by statement(s). Therefore, looking for effective assessment of students' conceptual understanding, we need to consider different ways to present the questions asked.

Nurrenbern et al.[3] set a test consisting of traditional problems, and conceptual questions involving diagrams, on stoichiometry and gases. Two hundreds students from two American universities took the test. The results of the test suggest that students have far greater success answering traditional questions than the conceptual questions. The students appeared having difficulty in understanding some fundamental concepts as these were revealed in their answers when they solved conceptual questions. For instance, two-third of the students tested did not really understand the critical attribute of gases, i.e. that gases occupy the entire volume of the container. While the students could recite the fact that gases have indefinite volume but they could not use this concept. They could solve the traditional problems about gases without knowing anything much about the nature of a gas. The discrepancies of students' performance on the two types of questions suggested that the students were weak in understanding chemistry concepts at a microscopic level. Sawrey[4] replicated the study in another university in United States and found the similar results as Nurrenbern et al.[3] did.

An Investigation of Conceptual Learning in Singaporean Students

Do our students here in Singapore have the same problem as described by Nurrenbern et al.[3] and Sawrey[4] that students have difficulty in understanding some

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fundamental chemical concepts? To answer this question a similar study to Nurrenbern et al.[3] but involving two different age groups of local students was undertaken. One group of the students involved 72 Pre-U-One chemistry students from one of the local junior colleges. Another group involved 83 pre-service chemistry student-teachers (science graduates who did chemistry in the university) from the National Institute of Education. Both groups were asked to work on 6 questions (Appendix). Out of the 6 questions, 4 were conceptual questions with diagrams and 2 were the traditional ones. Five questions (Q's 1, 2, 3, 4 & 6) were adapted from Nurrenbern et al.[3] The questions also asked students to give reasons for their answers. The topics involved in these questions were stoichiometry (Q's 1, 2, 3 & 4), conservation of mass (Q5), and particulate nature of a gas (Q6). The classification of these 6 questions into type and topic is shown in Table 1.

The numbers and percentages of students of the different groups: the overseas students[3], A-level students and student-teachers, with correct responses for each question are shown in Table 2. These results are also presented in a chart as shown in Fig. 1.

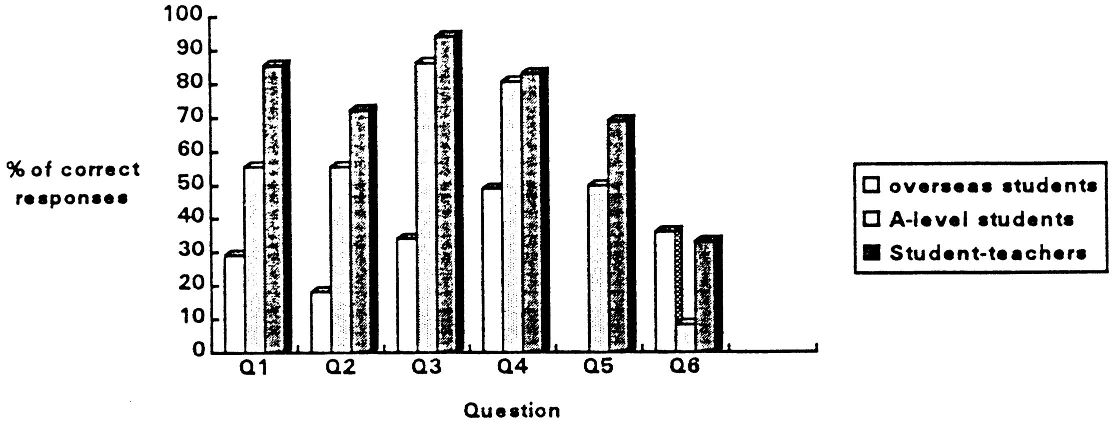
Table 1 Test questions and their types and topics

Question	Type	Topic
1	Conceptual	Stoichiometry
2	Conceptual	Stoichiometry
3	Traditional	Stoichiometry
4	Traditional	Stoichiometry
5	Conceptual	Conservation of mass
6	Conceptual	Particulate nature of a gas

Table 2 Numbers and percentages (in brackets) of students with correct responses

Questions	Overseas students N=200 (Q1-4) N=198 (Q6)	A-level students N=72	Student-Teachers N=83
1	58 (29.0)	40 (55.6)	71 (85.5)
2	35 (17.5)	40 (55.6)	60 (72.3)
3	67 (33.5)	62 (86.1)	78 (94.0)
4	98 (49.0)	58 (80.6)	69 (83.1)
5	-	36 (50.0)	57 (68.7)
6	72 (36.4)	6 (8.3)	27 (32.5)

Fig. 1 Percentages of the three groups of students with correct responses



It is shown from Table 2 and Fig. 1 that Singaporean students, the A-level and student-teachers, both had the same trend as the overseas students that they performed much better in the traditional type of problems (Q's 3 & 4) than the conceptual questions (Q's 1, 2, 5 and 6). Both groups were equally good and had very high success rate for Q's 3 & 4. This implies that the local students were generally well trained in answering traditional type of questions in schools or colleges. For all the questions, the student-teachers in general had relatively high success rate than the A-level students. This could probably be explained by their additional chemical education received in the university. Nevertheless, the success rate of the student-teachers did not seem to be outstanding especially for the conceptual questions despite the further chemical education in the university. There were still about 30 % or more student-teachers could not give the right answers (Q's 2, 5 and 6 in Table 2 or Fig. 1). Besides, among those who could correctly opted the answers, a reasonable number of them had difficulty to give reasons for their answers. These students either gave incomplete explanations or did not give any reason at all (Table 3). This indicated that our students were not generally well trained in giving explanations. The reason for this could be that much emphasis was given to the product (correct answer) rather than the process, by our educational system. Table 3 summarizes the nature of the reasons given by the student-teachers for each of the questions.

Some common misconceptions were identified from the student-teachers' explanations on the 6 questions. They are listed below under the topics: stoichiometry (Q's 1 - 4), conservation of mass (Q5) and particulate nature of a gas (Q6).

<u>Misconceptions in Stoichiometry (Q's 1 - 4)</u>

1. All reactants must react completely in a reaction. No excess of reactants should be left behind.

2. Unreacted chemicals can be included in a chemical reaction equation.
e.g. $3X + 8Y \rightarrow 3XY_2 + 2Y$

3. The law of conservation of mass was used to explain why the excess chemical should be present in a reaction equation.

Misconceptions in The Law of Conservation of Mass (Q5)

1. The disappearance of the substances involved in the reaction, e.g. air was used up; phosphorus reacted, contributes to the reduced weight. (The burning of phosphorus was undergoing in an air-tied flask containing some water.)

2. The white smoke produced in the reaction is lighter than the solid phosphorus before reaction, this contributes to the reduced weight.

3. Phosphorus dissolves in water instead of burning in the sun.

Misconceptions in Particulate Nature of a Gas (Q6)

1. -20^0 C was considered as very low temperature that the gas particles would turn to solid state in the following manners:

(a) the particles pack closely among themselves,
(b) the particles freeze, or
(c) the particles reduce the vibration due to lack of kinetic energy at low temperature.

Table 3 Nature of student-teachers' reasons for their correct responses

Question	No.of students with correct responses	Acceptable reason (%)	Misconception / wrong application (%)	No reason (%)	Incomplete reason (%)
1	72	43 (59.7)	0 (0)	6 (8.3)	23 (31.9)
2	60	28 (46.7)	2 (3.3)	9 (15.0)	21 (35.0)
3	78	61 (78.2)	1 (1.3)	16 (20.5)	0 (0)
4	69	67 (97.1)	0 (0)	2 (2.9)	0 (0)
5	57	44 (77.2)	6 (10.5)	7 (12.3)	0 (0)
6	27	11 (40.7)	4 (14.8)	6 (22.2)	6 (22.2)

What do these data tell us? The differences in the students' problem solving performance between the two types of questions: traditional and conceptual, did reflect how well the students learnt and understood the concepts or knowledge taught. The above evidence shows that students who are able to solve the numerical problems by plug-and-chug do not necessary conceptually understand the related chemical concepts. For instance, the students knew how to use the given equation to work out the limiting reagent and excess reactant for a reaction in the traditional question (Q3) and yet some appeared to have difficulty to relate the reaction equation to the particulate nature of the chemical involved (Q's 1 & 2). Many tend to hang onto the naive misconceptions. For instance, the students could not effectively apply the law of conservation of mass to a closed system as shown in Q5's diagram, instead they use their intuitive views on physical entity such as the absence of air or phosphorus or the formation of smoke, to determine if there was a change in weight after the reaction. From all this information, it does imply that our students like the overseas students[3,4] seem to have great difficulty in understanding fundamental concepts. The extra years of chemical learning experience do not seem to improve very much our students' conceptual understanding.

Implications

The present study is an additional piece of evidence showing how students' conceptual difficulties can be identified by using conceptual questions which are non-traditional and can probe for students' conceptual understanding. The questions could include pictorial presentation, such as using particles, to assess students' understanding at a microscopic level. Examples of this type of questions are illustrated in the Appendix. We agree that traditional questions in assessing students have their important role to play. But, if we are just satisfied with this type of questions, we, as instructors, will be frustrated, when our students repeat making the same mistakes again and again, or when they cannot apply scientific concepts correctly to solve problems from one situation to another.

We also agree that setting conceptual questions is not a simple task and is very time consuming. Someone may then argue that it may not be practical at the tertiary level. But, this is exactly the challenge for us, as science teachers/lecturers. If we admit our role to be a facilitator of students' learning, and are unable to effectively identify students' conceptual difficulties, how can we effectively facilitate our students' learning?

There is an additional advantage for us if we can incorporate conceptual questions in our instruction. Using this type of questions, our students' conceptual difficulties can be identified, monitored and remedied from time to time. Therefore, for the tertiary level, following such arrangement will have a positive effect on the present assessment system to evaluate students' academic performance. With respect to the setting of conceptual questions, we believe that cooperative work should be encouraged among staff with expertise in the same areas.

An important outcome of this research study is the extent to which certain chemistry concepts, e.g. the particulate nature of matter and stoichiometry, are not being comprehended by some junior college students and even those university graduates who had spent more years in studying chemistry. This implies that such misconceptions have been carried forwards by students after going through so many years of instruction. Its stubbornness to be changed and its reluctance to be replaced deserve special attention, if we want to enhance conceptual understanding in science instruction.

Another interesting observation, based on the students' response on reasoning, is that, in general, there is room for improvement on students' explaining skills. This may imply that during their process of learning, students may be left to chance in exercising these skills, because no explicit instruction is being given to them for such training. Therefore, such design of diagnostic instrument provides information for assessing certain process skills, especially explaining skills.

In conclusion, the mode of assessment deserves special attention when teaching science, if we want to effectively uncover students' conceptual understanding. We have also suggested that non-traditional ways of presenting conceptual questions could be incorporated into the instruction as one mode of assessment to find out students' conceptual understanding.

References

1. Driver, R., Guesne, E. & Tiberghien, A. (eds.) (1985) Children's ideas in science. Open University Press.

2. Osborne, R.J. & Freyberg, P. (eds.) (1985) Learning in science: the implications of children's science. Heinemann Educational Books.

3. Nurrenbern, S.C. & Pickering M. (1987) Concept learning versus problem solving: is there a difference? **Journal of Chemical Education,** 64 (6), 508-510.

4. Sawrey, B.A. (1990) Concept learning versus problem solving: revisited. **Journal of Chemical Education,** 67 (3), 253-254.

Acknowledgment

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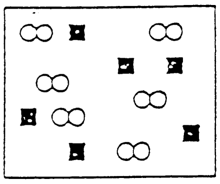
Appendix : Test Questions

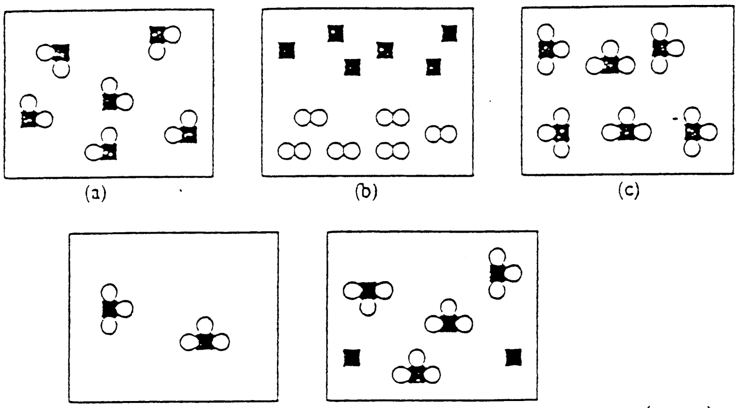
Q1

The equation for the reaction is $2S + 3O_2 \longrightarrow 2SO_3$. Consider a mixture of S (■) and O_2 (∞) in a closed container as illustrated below:



Starting Material

Which of the following represent the product mixture?

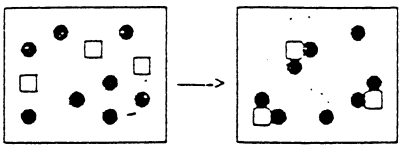


(a) (b) (c) (d) (e) ( )

Give the reason for your answer.

Q2

The reaction of element X (□) with element Y (●) is represented in the following diagram.



Which equation best describes this reaction?

(a) $3X + 8Y \longrightarrow X_3Y_8$
(b) $3X + 6Y \longrightarrow X_3Y_6$
(c) $X + 2Y \longrightarrow XY_2$
(d) $3X + 8Y \longrightarrow 3XY_2 + 2Y$
(e) $X + 4Y \longrightarrow XY_2$ ( )

Explain your answer.

Q3

A reaction equation can be written to represent the formation of water from hydrogen gas and oxygen gas.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

For a mixture of 2 moles H_2 with 2 moles O_2, what is the limiting reagent and how many moles of the excess reactant would remain unreacted after the reaction is completed?

	Limiting Reagent	Excess Reactants Remaining
(a)	O_2	1 mole O_2
(b)	O_2	1 mole H_2
(c)	H_2	1 mole O_2
(d)	H_2	1 mole H_2

( )

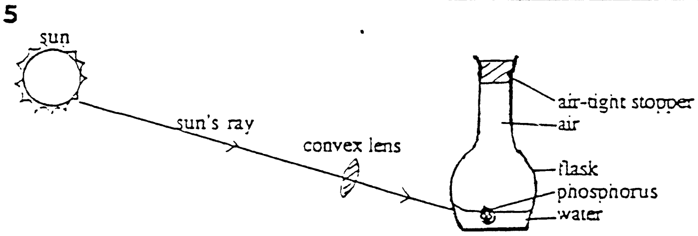
Explain your answer.

Q4

Calculate the maximum weight of SO_3 that could be produced from 1.9 moles of oxygen and excess sulfur. (Relative Atomic Mass of S = 32, O = 16)

$$2S + 3O_2 \longrightarrow 2SO_3$$

Q5



A piece of phosphorus was held in a flask as shown in the diagram. The mass of the flask and contents equaled 205 g. The sun's ray were focus on the phosphorus, which then caught fire. The white smoke produced slowly dissolved in the water.
After cooling, the flask and its contents were weighed again.

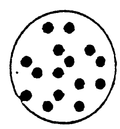
Would you expect the weight to be :

(a) more than 205 g
(b) 205 g
(c) less than 205 g
(d) not enough information to answer ( )

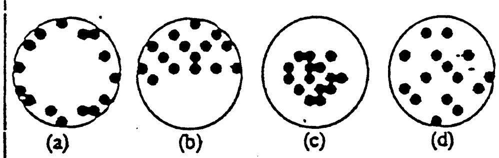
Give the reason for your answer.

Q6

The following diagram represents a cross-sectional area of a steel tank filled with hydrogen gas at 20°C and 3 atmosphere pressure. The dots represent the distribution of H_2 molecules.



Which of the following diagrams illustrate the distribution of H_2 molecules if the temperature of the steel tank is lowered to -20°C?



( )

Give the reason for your answer.