CHAPTER 5

FINDINGS AND DISCUSSION

5.0 Introduction

The general purpose of this study was to investigate Form four science students' representational competence of basic chemical concepts. The main aims of the study were: (i) to investigate students' understanding of basic chemical concepts, (ii) to evaluate their understanding of chemical representations, (iii) to assess their representational competence in chemistry, and (iv) to examine the influence of selected cognitive variables on their representational competence. A total of 411 Form four science students from seven urban secondary schools in Perak participated in this study. The sample size of the actual study (n=411) was smaller compared to what was intended (n=422). This is because some students were absent during the administration of one or more of the tests. Data for the study was obtained from seven instruments consisting of five paper-and-pencil tests, one questionnaire and interviews. Table 5.1 gives a summary of the instruments used, variables measured, and the corresponding sample size, in the actual study. The Statistical Package for the Social Sciences, SPSS was used to process and analyze quantitative data collected from the study.

In this chapter, findings are presented following the sequence of the research questions. Although both positive and negative findings were reported, it is believed that both kinds of findings will increase the understanding of representational competence among students. As was stated by an unknown author in an undated article:

"Research is not about finding proof but increasing understanding and negative findings can sometimes be more useful than positive ones."

Table 5.1
Instruments, variables, and the actual sample sizes

Instrument used	Variables measured	Sample size (n)
Test of Chemical Concept (TCC)	Understanding of chemical concepts	383
Test of Chemical Representations (TCR)	Understanding of chemical representations	379
Test of Representational Competence (TRC)	Representational competence	384
Classroom Test of Scientific Reasoning (CTSR)	Developmental level	214
Learning Approach Questionnaire (LAQ)	Learning orientation	213
Digit Span Backwards Test (DSBT)	Working memory capacity	209
Semi-Structured Interviews (SSI)	NA	9
Any one instrument	NA	411
All instruments*	NA	192

Note: NA - not applicable
* Not including SSI

5.1 Students' Understanding of Basic Chemical Concepts, Chemical Representations, and their Representational Competence

Pertaining to Research Question (i), this section reports the findings in three sub-sections. These are: (i) Students' overall levels of understanding of basic chemical concepts, (ii) Students' overall levels of understanding of chemical representations, and (iii) Students' overall levels of representational competence in chemistry.

5.1.1 A description of students' overall levels of understanding of basic chemical concepts

The mean, standard deviation, minimum, and maximum for Part A and Part B of the Test of Chemical Concepts (TCCa, TCCb), as well as the total TCC score (TCCt) of the 383 students are displayed in Table 5.2.

Table 5.2
Mean, standard deviation, minimum and maximum of TCC Scores (n=383)

Test score	Mean (%)	SD	Minimum (%)	Maximum (%)
TCCa	6.94 (46.27)	1.975	1 (6.67)	12 (80.00)
TCCb	6.74 (44.93)	2.883	1 (6.67)	14 (93.33)
TCCt	13.68 (45.60)	3.904	5 (16.67)	25 (83.33)

For TCCa, a mean score of 6.94 was obtained, with a standard deviation of 1.975. The overall TCCa score ranged from a minimum of 1 to a maximum of 12.

Students' performance in TCCb shows more variation in terms of scores. A mean score of 6.74 was recorded, with a standard deviation of 2.883. The overall TCCb score ranged from a minimum of 1 to a maximum of 14.

The TCCt score registered a mean score of 13.68, with a standard deviation of 3.904. The overall TCCt score ranged from a minimum of 5 to a maximum of 25.

On the whole, the mean TCCt score of 13.68 (or 45.60%), which falls below 50%, was rather low. Based on this score, it can be inferred that the overall levels of understanding of basic chemical concepts for this sample is unsatisfactory.

5.1.2 A description of students' overall levels of understanding of chemical representations

Table 5.3 shows the mean, standard deviation, minimum, and maximum for Part A and Part B of the Test of Chemical Representations (TCRa, TCRb), as well as the total TCR score (TCRt) of the 379 students who took the test in this study.

Table 5.3
Mean, standard deviation, minimum and maximum of TCR Scores (n=379)

Test scores	Mean (%)	SD	Minimum (%)	Maximum (%)
TCRa	15.23 (50.77)	2.719	7 (23.33)	24 (80.00)
TCRb	3.40 (56.67)	1.737	0 (0.00)	6 (100.00)
TCRt	18.63 (51.75)	3.274	7 (19.44)	27 (75.00)

The mean score for TCCa was 15.23, with a standard deviation of 2.719. The overall TCRa score ranged from a minimum of 7 to a maximum of 24.

For TCRb, the mean score was 3.40, with a standard deviation of 1.737. The overall TCRb score ranged from a minimum of 0 to a maximum of 6.

For TCRt, a mean score of 18.63 was registered, with a standard deviation of 3.274. The overall TCRt score ranged from a minimum of 7 to a maximum of 27.

On the whole, the mean TCRt score of 18.63 (or 51.75%), which is slightly above 50%, can be considered average. Based on this score, it can be deduced that the overall levels of understanding of chemical representations for this sample (n=379) is satisfactory.

5.1.3 A description of students' overall levels of representational competence in chemistry

The mean, standard deviation, minimum, and maximum for Part A and Part B of the Test of Representational Competence (TRCa, TRCb), as well as the total TRC score (TRCt) of the 384 students are shown in Table 5.4.

Table 5.4
Mean, standard deviation, minimum and maximum of TRC scores (n=384)

Test scores	Mean (%)	SD	Minimum (%)	Maximum (%)
TRCa	12.92 (51.68)	4.893	1 (4.00)	25 (100.00)
TRCb	3.98 (26.53)	3.533	0 (0.00)	15 (100.00)
TRCt	16.90 (42.25)	7.781	1 (2.50)	40 (100.00)

For TRCa, a mean score of 12.94 was recorded, with a standard deviation of 4.893. TRCa score ranged from a minimum of 1 to a maximum of 25.

A mean score of 3.98 was registered for TRCb, with a standard deviation of 3.533. TRCb score ranged from a minimum of 0 to a maximum of 15.

For TRCt, a mean score of 16.90 was obtained, with a standard deviation of 7.781. TRCt score ranged from a minimum of 1 to a maximum of 40.

On the whole, the mean TRCt score of 16.90 (or 42.25%), which falls below 50%, was rather low. Based on this score, it can be inferred that the overall levels of representational competence of the subjects in this study (n=384), is unsatisfactory.

However, three points are worth noting. These are: (i) despite the generally unsatisfactory performance of the subjects in the TRC, a maximum score of 100% was recorded for Part A (n=6), Part B (n=2), as well as the total TRC score (n=1), (ii) with the TRCt score ranging from a minimum of 1 to a maximum of 40, the subjects taking the TRC in this study (n=384) indeed show wide variation in their representational competence, and (iii) the subjects in this study performed much poorer in Part B of the TRC (mean TRCb=26.53%) compared to Part A of the TRC (mean TRCa=51.68%).

5.1.4 Section summary

Means for TCCt, TCRt and TRCt are respectively 45.60%, 51.75%, and 42.25%. The means for the three scores cannot be compared with previous research findings as the TCC, TCR, and TRC are all new instruments. Students' prior knowledge is the foundation upon which to build further knowledge. The low overall levels of understanding of students' basic chemical concepts and chemical representations reveal a weak foundation on which to build further chemical knowledge. Previous studies also have shown that students have difficulties understanding chemical concepts and chemical representations (Chittleborough & Treagust, 2007; Franco, 2005; Stains & Talanquer, 2007).

5.2 Comparing Students with Different Levels of Understanding of Chemical Concepts and Chemical Representations in their Representational Competence

Findings for research question (ii) shall be presented in three sub-sections. Section 5.3.1 gives a comparison of students with different levels of understanding of chemical concepts and their representational competence. Section 5.3.2 provides a comparison of students with different levels of understanding of chemical representations and their representational competence. Section 5.3.3 is the section summary.

5.2.1 Comparing students of different levels of understanding of chemical concepts in their representational competence

Although the number of students taking the TCC and TRC were 383 and 384 respectively, only those students who took both the tests (n=361) are included in this comparison.

Table 5.5
A comparison of students of different levels of understanding of chemical concepts in their representational competence

Levels of TCCt score	n	TRCt score			
		Mean	S.D. (s)	Minimum	Maximum
Low	52	12.38	4.598	4	29
Medium	202	14.46	5.813	1	31
High	107	23.74	7.870	5	40
Total	361	16.91	7.764	1	40

For the purpose of comparison, the students have been categorised into three levels of understanding of chemical concepts based on their TCCt scores. Ranges for the low (L), medium (M), and high (H) groups are based on quartiles of their TCCt scores (see *Appendix 28*). Sample size for the low, medium and high groups are n=52, n=202, and n=107, respectively.

The means reported in Table 5.5 show that students with a high level of TCCt score registered a much higher mean (23.74) in their TRCt score compared to the other two groups. The mean score of 23.74 almost double that of the low group (12.38). The results indicate that students with a high level of TCCt score outperformed the other two groups in their TRCt score. This implies that students with a high level of understanding of chemical concepts demonstrated the highest overall level of representational competence. The relatively small difference in the means (mean difference=2.08) between students with a medium level of TCCt score (mean=14.46) and those with a low level of TCCt score (mean=12.38) implies that these two groups of students do not differ much in their representational competence. Additionally, the relatively higher standard deviation (s.d.=7.870) of the TRCt score of the High group suggests there is more variation in representational competence among the subjects within the High group, as compared to the Low group (s.d.=4.598) and the Medium group (s.d.=5.813).

Graphically, the representational competence of the subjects (n=361) with different levels of understanding of chemical concepts can be compared using box plots, as shown in Figure 5.1.

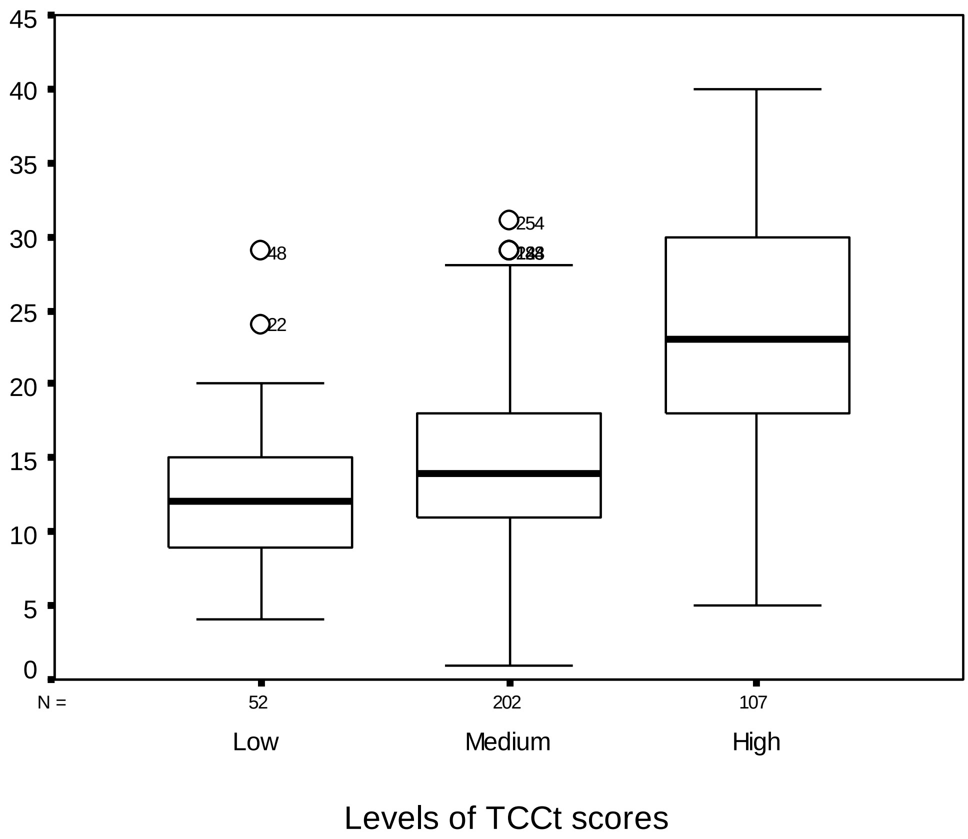


Figure 5.1: Box plots of TRCt scores for 3 levels of TCCt scores

Across the groups, Figure 5.1 shows that subjects with a higher level of TCCt scores register higher TRCt scores. This is evident from the value of the median and the maximum TRCt score, which is lowest for the low group and highest for the high group. While it is also obvious from Figure 5.1 that subjects with a high level of TCCt scores outperformed the other two groups in their representational competence (as reflected in their TRCt scores), there is relatively little difference in performance between subjects with low and medium levels of TCCt scores, in their representational competence. Although the maximum TRCt score for the medium and the low group (28 and 20 respectively) seem to differ greatly, the median for these two groups does not differ much. Essentially, the Low and the Medium group seem about equal in their representational competence.

For a box plot, the larger the box (or inter quartile range), the greater is the spread or standard deviation of the TRCt scores. Within the group, in terms of the distribution of TRCt scores, the small box sections for the Low and the Medium groups also indicate these two groups show little variation in their representational competence within their respective groups. Meanwhile, the High group has substantially more dispersion, as indicated by the much larger box section in the box plot (see Figure 5.1). This suggests that subjects in the High group show more variation in their representational competence within the group.

The researcher is also alerted by the presence of outliers by the box plots, as indicated by the notations at the upper portion of each plot beyond the whiskers (see Figure 5.1). However, the outliers were not deleted as statistical tests show that the outliers have no impact in the group differences.

To test whether there are significant differences in the representational competence among the three groups with different levels of understanding of chemical concepts, one-way analysis of variance (ANOVA) was performed. For the univariate test procedures of ANOVA to be valid in a statistical sense, assumptions for the use of ANOVA such as independence of observations, normality of data, as well as homogeneity of variance need to be assessed. The most fundamental assumption of ANOVA is normality. In this study, normality of data for TCCt scores and TRCt scores (n=361) was assessed using the normal probability plot, which compares the cumulative distribution of actual data values with the cumulative distribution of a normal distribution. The normal distribution forms a straight diagonal line, and the plotted data values are compared with the diagonal. If a distribution is normal, the line representing the actual data distribution closely follows the diagonal. Visual examination of the normal probability plots of TCCt scores and TRCt scores shows little or no violation of normality of data (Figure 5.1a).

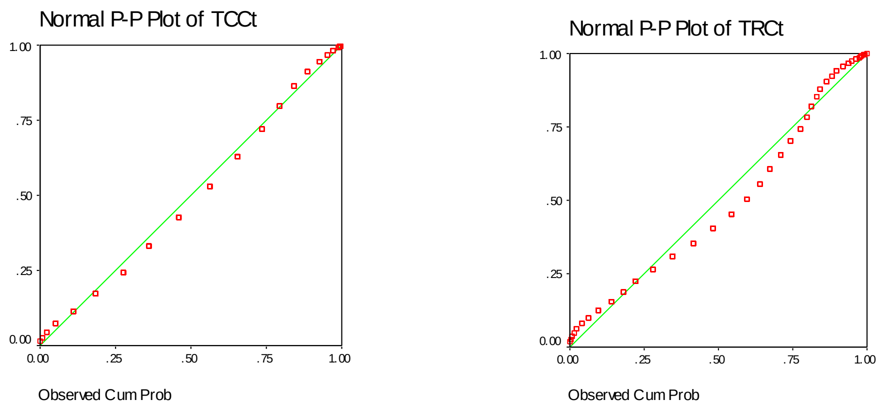


Figure 5.1a: Normal probability plots of TCCt scores and TRCt scores (n=361)

Table 5.6 presents the results of the one-way ANOVA. The results in Table 5.6 show that ANOVA was significant, [F (2, 358) = 90.10, p<0.001], indicating that there was a highly significant statistical difference in the mean of the TRCt scores among subjects of different levels of TCCt scores. This implies there were significant differences among subjects with different levels of understanding of chemical concepts in their representational competence in chemistry.

Table 5.6
ANOVA of TRCt scores for subjects with different levels of TCCt scores

Source of variation	Sum of square	df	Mean square	*F*-value	Level of significance
Between groups	7266.00	2	3605.745	90.100***	0.000
Within groups	14435.164	358	40.003		
Total	21701.163	361			

*** *F*-value is significant at $p < 0.001$

Post hoc tests for multiple comparisons, the Scheffe tests, were subsequently performed to determine which pair of means was significantly different. Results of the Scheffe test (Table 5.7) revealed significant differences between two pairs of TRCt means: High versus Low level of TCCt scores and High versus Medium level of TCCt scores, at $p < 0.001$. The mean difference between the pair of Medium versus Low level of TCCt scores was statistically not significant at $p < 0.05$.

Table 5.7
Multiple comparisons (Post Hoc Scheffe Tests) of TRCt mean scores

Levels of TCCt score (Pairs of groups compared)	Mean difference	Standard error	Level of significance
High vs Low	11.35***	1.073	0.000
High vs Medium	9.28***	0.759	0.000
Medium vs Low	2.08	0.987	0.111

*** The mean difference is significant at $p < 0.001$

The results in Table 5.7 further reveal that students with a high level of understanding of chemical concepts had significantly higher overall level of representational competence compared to both the medium and low groups, at $p<0.001$. However, subjects with medium and low levels of understanding of chemical concepts showed no significant difference in their overall levels of representational competence.

5.2.2 Comparing students of different levels of understanding of chemical representations in their representational competence

The number of subjects taking the TCR and TRC were 379 and 384 respectively. However, only those who took both the tests (n=352) are included in this comparison.

For the purpose of comparison, the subjects have been categorised into three levels of understanding of chemical representations based on their TCRt scores. Ranges for the low (L), medium (M), and high (H) groups are based on quartiles of their TCRt scores (see *Appendix 28*). Sample size for the low, medium and high groups are n=61, n=189, and n=102, respectively.

Table 5.8
A comparison of students of different levels of understanding of chemical representations in their representational competence

Levels of TCRt score	N	TRCt Score			
		Mean	s.d.	Minimum	Maximum
Low	61	13.59	5.433	3	29
Medium	189	16.17	6.961	2	36
High	102	20.14	8.879	1	40
Total	352	16.87	7.676	1	40

The means reported in Table 5.8 show that subjects with a high level of TCRt score registered the highest mean (20.14) in their TRCt score while students with a low level of TCRt score obtained the lowest mean (13.59) in their TRCt scores. This seems to imply that subjects with a high level of understanding of chemical representations demonstrated the highest overall level of representational competence. In terms of distribution of TRCt scores, the relatively higher standard deviation (s.d.=8.879) of the TRCt score of the High group suggests there is more variation in representational competence among the subjects within the High group, as compared to the Low group (s.d.=5.433) and the Medium group (s.d.=6.961).

Graphically, the representational competence of subjects with different levels of understanding of chemical representations can be compared using box plots, as shown in Figure 5.2.

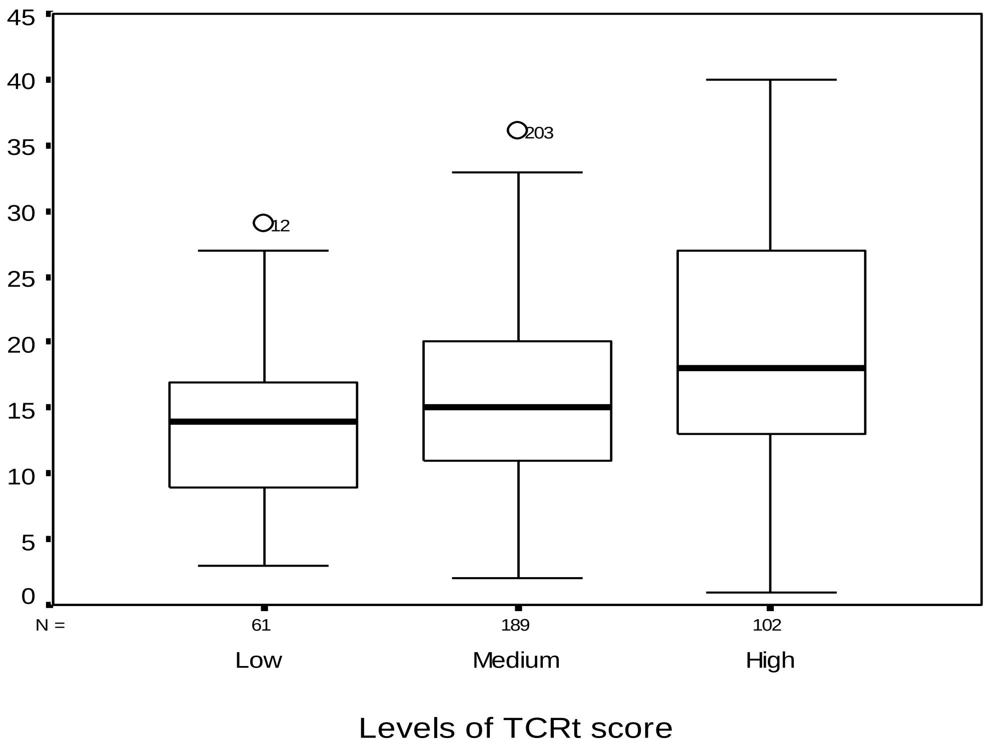


Figure 5.2: Box plots of TRCt scores for 3 levels of TCRt scores

Figure 5.2 shows that subjects with higher levels of TCRt scores register higher TRCt scores. This is indicated by the medians (the thick line within each box) and the maximum TRCt score (the upper whisker of each box), which is lowest for the Low group and highest for the High group.

Although Figure 5.2 shows that subjects with a high level of TCRt scores performed better compared to the other two groups in their representational competence, the performance among the three groups with different levels of TCRt scores in their representational competence does not differ greatly across the groups. In particular, the Low group and the Medium group are essentially equal in their representational competence.

In terms of distribution of TRCt scores within the group, only the High group show more variation in their TRCt scores or representational competence (as indicated by the larger box section in the box plot). The Low group and the Medium group show little variation in their representational competence within their respective groups.

The presence of outliers was indicated by the notations at the upper portion of each plot beyond the whiskers (see Figure 5.2). However, the outliers were retained as the statistical tests show that the outliers have no impact in the group differences.

To test whether there are significant differences in the representational competence among students with different levels of understanding of chemical representations, one-way analysis of variance (ANOVA) was performed. The most basic assumption of ANOVA, normality of data, was assessed.

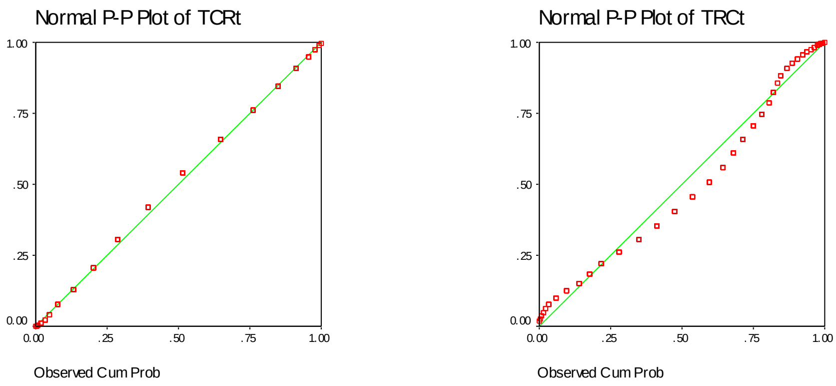


Figure 5.2a: Normal probability plots of TCRt scores and TRCt scores (n=352)

Normal probability plots of TCRt scores and TRCt scores (n=352) shows distribution of TCRt scores gives a normal distribution while distribution of TRCt scores follows closely a normal distribution (Figure 5.2a).

Table 5.9 presents the results of the one-way ANOVA of the TRCt score for the three groups with different levels of TCRt scores. The results in Table 5.9 show that ANOVA was significant, [F (2, 349) = 16.941, $p < 0.001$]. This indicates there were significant differences among subjects with different levels of understanding of chemical representations in their representational competence in chemistry.

Table 5.9
ANOVA of TRCt scores for students with different levels of TCRt scores

Source of variation	Sum of square	df	Mean square	*F*-value	Level of significance
Between groups	18118.305	2	909.152	16.941***	.000
Within groups	18729.150	349	53.665		
Total	20547.455	351			

*** *F*-value is significant $p < 0.001$

Post hoc tests for multiple comparisons, the Scheffe tests, were subsequently performed to determine which pair of means was significantly different. Results of the Scheffe test (Table 5.10) revealed significant differences between two pairs of TRCt means: High versus Low level of TCRt scores and High versus Medium level of TCRt scores, at $p < 0.001$. The mean difference between the pair of Medium versus Low level of TCRt scores was statistically not significant at $p < 0.05$.

Table 5.10
Multiple comparisons (Post Hoc Scheffe Tests) of TRCt mean scores

Levels of TCRt score (Pairs of groups compared)	Mean difference	Standard error	Level of significance
High vs Low	6.52***	1.186	.000
High vs Medium	3.94***	.900	.000
Medium vs Low	2.58	1.079	.059

*** The mean difference is significant $p < 0.001$

The results in Table 5.10 further indicate that students with a high level of understanding of chemical representations had significantly higher overall level of representational competence compared to both the medium and low groups, at $p<0.001$. However, students with medium and low levels of understanding of chemical representations showed no significant difference in their overall levels of representational competence.

5.2.3 Section summary

Students with a high level of understanding of chemical concepts had significantly higher overall level of representational competence compared to both the medium and low groups. However, students with medium and low levels of understanding of chemical concepts showed no significant difference in their overall levels of representational competence. Students with a high level of understanding of chemical representations also had significantly higher overall level of representational competence compared to both the medium and low groups while those with medium and low levels of understanding of chemical representations showed no significant difference in their overall levels of representational competence. However, a thorough literature search did not reveal any comparison as has been done in this section.

5.3 Form Four Students' Alternative Conceptions of: (i) Basic Chemical Concepts and (ii) Chemical Representations

The following sub-sections examine form four students' alternative conceptions of chemical concepts and chemical representations. Section 5.3.1 focuses on students' alternative conceptions of chemical concepts while a description of students' alternative conceptions of chemical representations is given in Section 5.3.2.

5.3.1 Form four students' alternative conceptions of basic chemical concepts

This sub-section focuses on students' alternative conceptions of chemical concepts. Table 5.11 displays the percentage of alternative conceptions for the 30 items in the TCC. Table 5.12 gives the percentage of mean alternative conceptions for the TCC by category of chemical concepts, while Table 5.13 summarises items in the TCC with alternative conceptions exceeding 50%.

Table 5.11
Percent alternative conception for items in the TCC by category of chemical concept (n=383)

Item No.	Chemical Concepts (by category)	Correct Responses		% Alternative Conceptions
		Frequency	%	
A1	Pure substances and mixtures	64	16.71	**83.29**
A2	Atoms, molecules and ions	251	65.54	34.46
A3	Elements and compounds	262	68.41	31.59
A4	Atoms, molecules and ions	182	47.52	**52.48**
A5	Pure substances and mixtures	206	53.79	46.21
A6	Physical change and chemical change	122	31.85	**68.15**
A7	Physical change and chemical change	266	69.45	30.55
A8	Elements and compounds	77	20.10	**79.90**

Table 5.11 (continued)

Item No.	Chemical Concepts (by category)	Correct Responses Frequency	%	% Alternative Conceptions
A9	Elements and compounds	111	28.98	**71.02**
A10	Atoms, molecules and ions	211	55.09	44.91
A11	Isotopes	268	69.97	30.03
A12	Chemical bonds	116	30.29	**69.71**
A13	Sub-atomic particles	87	22.72	**77.28**
A14	The mole concept	238	62.14	37.86
A15	Atoms, molecules and ions	174	45.43	**54.57**
B1	Atoms, molecules and ions	143	37.34	**62.66**
B2	Atoms, molecules and ions	239	62.40	37.60
B3	Atoms, molecules and ions	217	56.66	43.34
B4	Electron arrangement and valence electron	107	27.94	**72.06**
B5	Pure substances and mixtures	172	44.91	**55.09**
B6	Proton number and nucleon number	184	48.04	**51.96**
B7	Physical change and chemical change	73	19.06	**80.94**
B8	Elements and compounds	266	69.45	30.55
B9	Sub-atomic particles	162	42.30	**57.70**
B10	Chemical bond	282	73.63	26.37
B11	Atoms, molecules and ions	105	27.42	**72.58**
B12	Physical change and chemical change	172	44.91	**55.09**
B13	Conservation of mass	118	30.81	**69.19**
B14	The mole concept	239	62.40	37.60
B15	Matter and its properties	108	28.20	**71.80**

Table 5.12
Percent mean alternative conceptions for the TCC by category of chemical concepts (n=383)

Chemical Concept (by Category)	Item No.	% Alternative Conception	
1. Matter and its properties	B15	**71.80**	
2. Pure substances and mixtures	A1	**83.29**	
	A5	46.21	
	B5	**55.09**	
			61.53*
3. Elements and compounds	A3	31.59	
	A8	**79.90**	
	A9	**71.02**	
	B8	30.55	
			53.27*
4. Atoms, molecules and ions	A2	34.46	
	A4	**52.48**	
	A10	44.91	
	A15	**54.57**	
	B1	**62.66**	
	B2	37.60	
	B3	43.34	
	B11	**72.58**	
			50.33*
5. Physical change and chemical change	A6	**68.15**	
	A7	30.55	
	B7	**80.94**	
	B12	**55.09**	
			58.68*
6. Conservation of mass	B13	**69.19**	
7. Sub-atomic particles	A13	**77.28**	
	B9	**57.70**	
			67.49*
8. Proton no. and nucleon no.	B6	**51.96**	
9. Isotopes	A11	30.03	
10. Electron arrangement and valence electrons	B4	**72.06**	
11. The mole concept	A14	37.86	
	B14	37.60	
			37.73*
12. Chemical bond	A12	**69.71**	
	B10	26.37	
			48.04*

* *denotes percent mean*

Table 5.11 shows 18 out of the 30 items (or 60%) have percentage alternative conception exceeding 50%. This high percentage of alternative conception is perhaps not surprising since the overall levels of understanding of basic chemical concepts for this sample is also below average, as reflected by the mean TCCt score of 13.68 or 45.60% (see Section 5.1.1).

From Table 5.12, it could be seen that the mean or percent mean alternative conceptions for 9 of the 12 categories of basic chemical concepts exceed 50%. In addition, the mean or percent mean alternative conceptions for the first 5 categories of the most basic chemical concepts all exceed 50%. Of the 20 items in the first 5 categories, 12 of the items (or 60%) registered alternative conceptions exceeding 50%. Percent alternative conception is as high as 70% to 80% for 6 of the items (B15, A1, A8, A9, B11, B7). This high percentage not only reflects alternative conceptions of the most basic chemical concepts are very common among Form four science students but also the low level of understanding of basic chemical concepts among Form four science students. Both these issues are cause for concern because in the absence of a sound mental picture of basic chemical concepts, there is no foundation upon which to build advanced concepts (Nakhleh & Krajcik, 1994).

A more detailed analysis on students' alternative conceptions identified from their responses in the TCC is now discussed. Please refer to Tables 5.13 and 5.14.

Table 5.13
Items in the TCC with alternative conceptions exceeding 50%
(ranked in descending order)

Ranking	Item No.	Alternative Conception	% Alternative Conceptions
		Pure substances and mixtures	
1	A1	Believed that the simplest substances in chemistry are atoms. <u>The problem</u> Either do not know the meaning of the term \`substance', or regarded the terms \`atom' and \`element' as referring to the same meaning.	**83.29**
		Physical change and chemical change	
2	B7	Disregard for particle conservation when describing chemical change. <u>The problem</u> Do not know what a chemical change is, or do not know what actually happens during a chemical change, or both.	**80.94**
		Elements and compounds	
3	A8	Believed that the particles in a compound can be atoms, molecules, or ions. <u>The problem</u> Either do not know atoms can only be the particles in elements, or do not know particles in a compound can only be molecules or ions, or both.	**79.90**
		Sub-atomic particles	
4	A13	Believed that all atoms can be identified by the number of protons they contain. <u>The problem</u> Not aware that it is possible for atoms of the same element to have the same number of protons but different number of neutrons (isotopes), or do not have a clear conceptual understanding of the term \`isotope'.	**77.28**

Table 5.13 (continued)

Ranking	Item No.	Alternative Conception	% Alternative Conceptions
		Atoms, molecules and ions	
5	B11	Believed that the type of particles in helium gas and hydrogen gas are the same (48.56%), or believed that the particles are different but do not know why (22.19%). The problem No clear idea about particles of matter.	**72.58**
		Electron arrangement and valence electrons	
6	B4	Believed that the number of valence electrons of an oxide ion is 6 (option C=42.30%), or -2 (option A=18.28%), or 4 (option B=11.49%). The problem Option C: Do not understand the concept of valence electron, or having no idea about electron arrangement, or both. Option A: Confused between valence electron and charge of an ion. Option B: No clear idea about the concept of `ion'.	**72.06**
		Matter and its properties	
7	B15	Perceived particles as mini-versions of the substances they comprise. The problem Thought that particles possess the same properties as the materials they compose.	**71.80**
		Elements and compounds	
8	A9	Regarded both water, H_2O, and ozone, O_3, as molecular compounds. The problem Tend to associate or link the concept `molecule' with `compound'., or cannot read and interpret chemical formula as formula for ozone, O_3 is given.	**71.02**

Table 5.13 (continued)

Ranking	Item No.	Alternative Conception	% Alternative Conceptions
		Chemical bonds	
9	A12	Believed that atoms take part in the formation of chemical bond to neutralise their charges. <u>The problem</u> Do not understand the concept of chemical bonds or the rationale behind chemical bonding, or associate chemical bonding with ionic bonds only, and formation of ions of opposite charges.	**69.71**
		Conservation of mass	
10	B13	Absence of conservation of mass during a chemical change. <u>The problem</u> Frequent disregard for particle conservation when describing chemical change.	**69.19**
		Physical change and chemical change	
11	A6	Believed that sugar dissolving in water is a chemical change. <u>The problem</u> Cannot distinguish between physical change and chemical change.	**68.15**
		Atoms, molecules and ions	
12	B1	Believed that atoms are not electrically neutral (45.70%) or believed that atoms are electrically neutral but do not know why (16.45%). <u>The problem</u> Do not understand the concept `atom', or do not know the composition of sub-atomic particles within an atom.	**62.15**
		Sub-atomic particles	
13	B9	Believed that the identity of an element is determined by the number of protons and neutrons (37.34%), or electron (14.10%), or neutrons (6.27%). <u>The problem</u> Probably confused between the concepts `atom' and `element'.	**57.70**

Table 5.13 (continued)

Ranking	Item No.	Alternative Conception	% Alternative Conceptions
		Pure substances and mixtures	
14	B5	Regarded bronze as a pure substance. <u>The problem</u> Do not know the meaning of "pure substance" or unfamiliar with the substance "bronze", or thought that bronze is also a pure substance.	**55.09**
		Physical change and chemical change	
14	B12	Believed that "expansion of matter is due to the expansion of particles rather than to increased particles spacing." <u>The problem</u> Have little or no idea about particles of matter, or the arrangement of particles within matter, or both.	**55.09**
		Atoms, molecules and ions	
16	A15	Believed that the particles in magnesium ribbon are not neutral atoms. <u>The problem</u> Do not know or unsure of the type of particles in a common substance.	**54.57**
		Atoms, molecules and ions	
17	A4	Believed that positive ions are formed when neutral atoms gain proton(s). <u>The problem</u> The concept of formation of ions from neutral atoms, that is: atom +/- e → ions, or more specifically, Atom + e → negative ion, Atom – e → positive ion, is not well understood.	**52.48**
		Proton number and nucleon number	
18	B6	Regarded positive charge as due to the presence of proton. Hence, relate a charge of 3+ as equivalent to 3 additional protons. <u>The problem</u> Do not understand the concept `proton number'.	**51.96**

Table 5.14
Students' responses to the Test on Chemical Concepts (TCC) Part B

Item No.	Frequency(n) and Percentages(%) of Responses									
	A		**B**		**C**		**D**		**Omit**	
	n	%	n	%	n	%	n	%	n	%
B1	63	16.45	**143**	**37.34**	106	27.68	69	18.02	2	0.52
B2	37	9.66	64	16.71	**239**	**62.40**	38	9.92	5	1.31
B3	110	28.72	**217**	**56.66**	46	12.01	5	1.31	2	0.52
B4	70	18.28	44	11.49	162	42.30	**107**	**27.94**	0	0.00
B5	**172**	**44.91**	31	8.09	26	6.79	150	39.16	3	0.78
B6	**184**	**48.04**	16	4.18	148	38.64	33	8.62	2	0.52
B7	83	21.67	129	33.68	95	24.80	**73**	**19.06**	1	0.26
B8	**266**	**69.45**	50	13.05	43	11.23	21	5.48	2	0.52
B9	**162**	**42.30**	54	14.10	24	6.27	143	37.34	1	0.26
B10	12	3.13	52	13.58	**282**	**73.63**	34	8.88	0	0.00
B11	82	21.41	104	27.15	85	22.19	**105**	**27.42**	1	0.26
B12	64	16.71	47	12.27	99	25.85	**172**	**44.91**	0	0.00
B13	139	36.29	59	15.40	**118**	**30.81**	64	16.71	3	0.78
B14	89	23.24	34	8.88	**239**	**62.40**	19	4.96	0	0.00
B15	56	14.62	**108**	**28.20**	85	22.19	130	33.94	1	0.26

Note: Key in bold

In the category *Matter and its properties*, 71.80% of the subject perceived particles as mini-versions of the substances they comprise (item B15). This problem may arise because students thought that particles possess the same properties as the materials they compose. For example: one single atom of sulphur is brittle, crystalline solid, has melting point of 113^{o}C (see Table 5.13); an atom of copper is malleable (Ben-Zvi, Eylon, & Silberstein, 1986), atoms of copper are "orange and shinny", gas molecules are transparent, and molecules of solid are hard. This finding is also consistent with those of Anderson (1990). They found students often transfer the macroscopic properties of a substance to its submicroscopic particles. For example: observing that sulphur is yellow, so believe that the atoms of sulphur are yellow also. However, when considering the graphic representation of yellow circles in many chemistry textbooks to represent sulphur atoms, this is not at all surprising.

More alternative conceptions were detected in the category of *pure substances and mixtures*. In item A1, 83.29% of the subjects believed that the simplest substances in chemistry are atoms. This could be because students either do not know the meaning of the term `substance', or regarded the terms `atom' and `element' as referring to the same meaning. That is: cannot distinguish between `atom'- a submicroscopic entity, and `element'- a macroscopic term, and cannot relate the two concepts. In item B5, the nature of the alternative conception differs. 55.09% of the subjects regarded bronze as a pure substance. The problem could have arisen because students do not know the meaning of "pure substance", or not familiar with the substance "bronze", or the fact that the three substances gold, silver, and bronze are often seen together could have led students to think that since gold and silver are pure substances, bronze is also a pure substance. However, according to previous researchers, the language of chemistry could possibly cause the problem. This is because within chemistry, there are several meanings for the same word and students confronted with the same words with different meanings become confused (Selinger, 1998, cited in Treagust, Duit, & Niewandt, 2000). For example: `pure' can refer to the cleanliness of a substance, not its chemical nature; `mixture' refers to something physically combined together, not the chemical nature of, for example, glass, blood, or drinking water. Students' experiences are mainly with mixtures; however, their perception is that these substances such as bronze, brass, wine, tap water, are chemically pure. Fensham (1994) also pointed out that words as different as dissolving and melting, which are obvious to teachers, are frequently confused when used by students who have insufficient background or experience with which to distinguish these terms and consequently the teachers' meaning is not communicated clearly. Unfortunately, in the classroom, often no distinction is made between the scientific meaning and the commonplace meaning of vocabulary, assuming that students understand the special chemical meanings of the terms being used (Nakhleh & Krajcik, 1994; Schmidt, 1997).

In the category of *elements and compounds*, 79.90% of the subjects (item A8) believed that the particles in a compound can be atoms, molecules, or ions. Students either do not know atoms can only be the particles in elements, or they do not know particles in a compound can only be molecules or ions. In item A9, 71.01% of the subjects regarded both water, H_2O, and ozone, O_3, as molecular compounds. It seems students tend to associate or link the concept `molecule' with `compound', or they have difficulty reading and interpreting chemical formula as formula for ozone, O_3 is given. This finding supports that of Fensham (1994), who found students tend to associate elements with atoms and molecules with compounds. More recent researches share similar findings (Chittleborough & Treagust, 2007; Stains & Talanquer, 2007).

The category with the most basic concepts of *atoms, molecules and ions* appears to be the most problematic area. Four of the items recorded alternative conception exceeding 50%. In item A4, 52.48% of the subjects believed that positive ions are formed when neutral atoms gain proton(s). These students probably do not understand the concept of formation of ions from neutral atoms, that is: when an atom gains or loses electron(s), an ion is formed, or more specifically: when an atom gains electron(s), a negative ion is formed; when an atom loses electron(s), a positive ion is formed. In item A15, 54.57% of the subjects thought that the particles in magnesium ribbon are not neutral atoms. These students still do not know or unsure of the type of particles in a common substance like magnesium. In item B1, 45.70% of the subjects believed that atoms are not electrically neutral or believed that atoms are electrically neutral but do not know why (16.45%). Hence, a total of 62.66% of the subjects either do not understand the concept `atom', or do not know the composition of sub-atomic particles within an atom. Furthermore, in item B11, 48.56% of the subjects believed that the type of particles in helium gas and hydrogen gas are the same, or believed that the particles are different but do not know why (22.19%). Thus, a total of 72.58% of the subjects had no clear idea about particles of matter. The above findings lend support to previous researches that particular words such as particle, molecule, ion, atom, and substance are often misused and misinterpreted. Harrison and Treagust (2000) point out that for many Grade 8 students and even for some Grade 8 to 10 science teachers, their understanding of the particulate nature of matter, that is: the submicroscopic level, is poor. Chittleborough (2004) also found that although the particulate nature of matter forms the foundation of all chemical explanations, it is often assumed that students accept and understand the concept of the particulate nature of matter.

In the simple category of *physical change and chemical change*, 68.15% of the subjects (item A6) believed that sugar dissolving in water is a chemical change. These students probably cannot distinguish between physical change and chemical change. In item B7, 80.94% of the subjects disregarded particle conservation when describing chemical change. These students either do not know what a chemical change is, or do not know what actually happens during a chemical change, or both. In addition, in item B12, 55.09% of the subjects believed that "expansion of matter is due to the expansion of particles rather than to increased particles spacing."

Probably, these students have little or no idea about particles of matter, or the arrangement of particles within matter, or both. These findings support many previous research findings which found even prospective chemistry teachers (Gabel, 2000), college students (National Research Council, 1996), and university students (Bodner, 1987) had poor conceptual understanding of physical change and chemical change.

In the category of *conservation of mass*, 69.19% of the subjects assumed absence of conservation of mass during a chemical change. Such students have frequent disregard for particle conservation when describing chemical change.

For the category of *sub-atomic particles*, 77.28% of the subjects (item A13) believed that all atoms can be identified by the number of protons they contain. These students were not aware that it is possible for atoms of the same element to have the same number of protons but different number of neutrons (isotopes), or they do not have clear conceptual understanding of the term `isotope'. Confusion between the concepts "atom" and "element" might also have contributed to their wrong conception. In item B9, students believed that the identity of an element is determined by the number of protons and neutrons (option D=37.34%), or electron (option B=14.10%), or neutrons (option C=6.27%). These students were probably confused between the concepts `atom' and `element', as the identity of an atom is determined by the number of protons and neutrons whereas the identity of an element is determined by the number of protons only.

In the category of *proton number and nucleon number*, 51.96% of the subjects (item B6) regarded positive charge as due to the presence of proton. Hence, relate a charge of 3+ as equivalent to 3 additional protons. These students probably do not understand the concept `proton number'.

For the category of *electron arrangement and valence electron* (item B4), 42.30% of the subjects believed that the number of valence electrons of an oxide ion is 6 (option C), or -2 (option A=18.28%), or 4 (option B=11.49%). Such students either do not understand the concept of valence electron, or having no idea about electron arrangement (option C), or both; confused between valence electron and charge of an ion (option A); no clear idea about the concept of `ion' (option B).

For the category of *chemical bonds*, 69.71% of the subjects believed that atoms take part in the formation of chemical bond to neutralise their charges. Such students either do not understand the concept of chemical bonds or the rationale behind chemical bonding. They tend to associate chemical bonding with ionic bonds only, and formation of ions of opposite charges.

Hence, having difficulty distinguishing and inter-relating even the basic chemical concepts of atom and element, molecules and compounds, compounds and mixture can cause storage problem within the LTM. When the network of concepts in the form of schemata within the LTM are incorrectly linked or wrongly established, many alternative conceptions may arise.

5.3.2 Form four students' alternative conceptions of chemical representations

This sub-section provides a description of students' alternative conceptions of chemical representations. Table 5.15 shows the percentage of alternative conceptions for the 36 items in the TCR, Table 5.16 gives the percent mean alternative conceptions for the TCR by content domain, while Table 5.17 summarises items in the TCR with alternative conceptions exceeding 50%.

Table 5.15
Percent alternative conceptions for items in the TCR (n=379)

Item no.	Correct responses Frequency	%	% alternative conceptions
A1	146	38.42	**61.58**
A2	310	81.58	18.42
A3	240	63.16	36.84
A4	144	37.89	**62.11**
A5	111	29.21	**70.79**
A6	290	76.32	23.68
A7	261	68.68	31.32
A8	271	71.32	28.68
A9	102	26.84	**73.16**
A10	112	29.47	**70.53**
A11	97	25.53	**74.47**
A12	140	36.84	**63.16**
A13	243	63.95	36.05
A14	252	66.32	33.68
A15	90	23.68	**76.32**
A16	86	22.63	**77.37**
A17	239	62.89	37.11
A18	258	67.89	32.11
A19	201	52.89	47.11
A20	64	16.84	**83.16**
A21	106	27.89	**72.11**
A22	242	63.68	36.32
A23	213	56.05	43.95
A24	276	72.63	27.37
A25	242	63.68	36.32
A26	192	50.53	49.37
A27	252	66.32	33.68
A28	171	45.00	**55.00**
A29	209	55.00	45.00
A30	214	56.32	43.68
B1	224	58.95	41.05
B2	199	52.37	47.63
B3	170	44.74	**55.26**
B4	197	51.84	48.16
B5	233	61.32	38.68
B6	268	70.53	29.47

Table 5.15 shows only 13 out of 36 items (or 36% of the items) have percentage alternative conception exceeding 50%. This percentage of alternative conception is much lower compared to that of the TCC (60%). Perhaps students' conception of chemical representations is better compared to their conceptions of

basic chemical concepts. This appears reasonable as the mean TCR score of 18.63 (51.75%) is also higher compared to the TCC means (13.68 or 45.60%).

Table 5.16
Percent mean alternative conceptions for the TCR (by content domain)

Chemical Representations (by content domain)	Item No.	% Alternative Conception	
1. The 3 levels of representation of matter	A4	**62.11**	
	A9	**73.16**	
	A10	**70.53**	
	A15	**76.32**	
	A16	**77.37**	
	A21	**72.11**	
			71.93*
2. Chemical symbols	A1	**61.58**	
	A2	18.42	
	A5	**70.79**	
	A8	28.68	
	B5	38.68	
	B6	29.47	
			41.27*
3. Chemical formula	A3	36.84	
	A7	31.32	
	A11	**74.47**	
	A14	33.68	
	A17	37.11	
	A18	32.11	
	A20	**83.16**	
	A22	36.32	
	A23	43.95	
	A29	45.00	
	A30	43.68	
	B1	41.05	
	B2	47.63	
	B3	**55.26**	
			45.83*
4. Models	A13	36.05	
	A19	47.11	
	A24	27.37	
	A25	36.32	
			36.71*
5. Chemical equations	A6	23.68	
	A12	**63.16**	
	A26	49.37	
	A27	33.68	
	A28	**55.00**	
	B4	48.16	
			45.51*

** denotes percent mean*

Table 5.16 shows “the three levels of representation of matter” is the content domain with the highest percent mean alternative conception (71.93%). In addition, percent alternative conceptions of all the 6 items in that content domain exceed 60%. For 5 of the 6 items, percent alternative conceptions even exceed 70% (see Table 5.16). The content domain with the lowest percent mean alternative conception is `models’ (36.71%). Percent alternative conceptions of all the 4 items in that content domain are also below 50%. A comparison of the percent mean alternative conceptions for the five content domains seems to suggest that the three levels of representation of matter is the most problematic area of chemical representations for this sample of students, whereas `model’ appears to be the least problematic area. With percent mean difficulty all exceeding 40%, the other three content domains of chemical symbols (41.27%), chemical formula (45.83%), and chemical equations (45.51%) are just manageable.

The three levels of representation of matter has always been a problem area in many other studies as well (Gabel, 1993, 1998, 1999; Harrison & Treagust, 1996; Johnstone, 1997). This problem is also detected in the present study, which is indicated by the high percentages of students having the wrong response(s) for items A4, A9, A10, A15, A16 and A21 (Table 5.15), or the high percentage of them having alternative conceptions for these items (Table 5.16). The result is consistent with the findings by previous studies (Arasasingham, Taagepera, Potter, & Lonjers, 2004; Devetak, Urbancic, Wissiak Grm, Krnel, & Glazar, 2004; Heitzam & Krajcik, 2005; Lynthcott, 1990; Nakhleh, 1992, 2002; Sawrey, 1990; Sim, 2006, and Yarroch, 1985) which found students had difficulties coping with the three levels of representations, in particular, conceptualizing at a molecular level.

Table 5.17 highlights the 13 items with alternative conceptions exceeding 50%.

Table 5.17
Items in the TCR with alternative conceptions exceeding 50% (ranked in descending order)

Ranking	Item No.	Alternative Conception	% Alternative Conceptions
1	A20	Believed that $C_6H_{12}O_6$ is glucose.	**83.16**
2	A16	Regarded Na=2.8.1, so sodium loses electron to form sodium ion.	**77.37**
3	A15	Thought that magnesium has a charge of +2.	**76.32**
4	A11	Believed that in the water molecule (H_2O), a hydrogen molecule, H_2, is bonded to an oxygen atom, O.	**74.47**
5	A9	Believed that copper atoms are reddish brown.	**73.16**
6	A21	Thought that when hydrogen loses an electron, hydrogen ion, H^+, is formed.	**72.11**
7	A5	Believed that the symbol for chlorine in chlorine gas is `Cl_2'.	**70.79**
8	A10	Perceived that chlorine has 7 valence electrons.	**70.53**
9	A12	Regarded chemical equation as a representation of a chemical reaction using chemical formula only.	**63.16**
10	A4	Believed that chlorine molecules are greenish-yellow.	**62.11**
11	A1	Believed that H_2 and O_2 are symbols of the elements hydrogen and oxygen respectively.	**61.58**
12	B3	Thought that the number of atoms of boron represented by "$6Na_2B_4O_7$" is 4 (option A, 18.99%) or 6 (option B, 26.39%) or 10 (option C, 9.50%).	**55.26**
13	A28	Believed that the plus sign (+) on both sides of a chemical equation has the same meaning.	**55.00**

With regards to alternative conceptions in the content domain of *the three levels of representation of matter*, two main problems were identified.

Firstly, there is problem with the use of particulate terms such as atom, ion, and molecules (see items A10, A15, A16, and A21). For example: In item A10, the correct conception should be `chlorine atom has 7 valence electrons'; in item A15, the correct statement should be `magnesium ion has a charge of 2+'; item A16 should read `the electron arrangement of sodium atom is 2.8.1, so sodium atom loses one electron to form sodium ion', and item A21 should be `when hydrogen atom loses an electron, hydrogen ion is formed'. In each of these four items, the particulate term was deliberately left out, but students could not detect the missing term. It seems students had no clear idea about the particles of matter, not aware of their importance, or do not understand the concept of the particulate nature of matter. Probably their understanding of the submicroscopic level is poor as very often, classroom teaching focus on the macroscopic and emphasizes on symbolic representations such as symbols, formulae, equations, models, leaving the imaginary submicroscopic world of atoms, molecules, and ions to the students. Harrison and Treagust (2000) point out that for many Grade 8 students and even for some Grade 8 to 10 science teachers, their understanding the submicroscopic level is poor. The lack of a mental model of many novice students appears to be a result of the submicroscopic level being ignored or marginalised when compared to the macroscopic and symbolic levels of representation. Although there are now more emphasis on the abstract symbolic and submicroscopic levels (Fensham, 1994), students still have problem linking the macroscopic and submicroscopic levels. Chemistry is often taught on the symbolic level using materials that are unfamiliar to students (Gabel, 2000). Since chemical concepts are represented at three levels –

macroscopic, submicroscopic, and symbolic, confusion between the macroscopic and submicroscopic nature of matter gives rise to students confusing chemical phenomena such as: (i) dissolving and melting, (ii) having difficulty accepting the conservation of matter and mass when some substances appears to disappear, and (iii) accepting the `disappearance' of liquids during evaporation (Anderson, 1990). This problem is also very well reflected by students' low overall level of understanding of basic chemical concepts (Section 5.1.1) and their many alternative conceptions of basic chemical concepts (Section 5.3.1). Unless explicitly taught, students cannot establish their own links between the three levels for portraying the chemical phenomena. Unfortunately, explanations are nearly always at the submicroscopic level – a level that cannot be observed but can be described and explained using symbols. Explaining chemical reactions demands that a mental picture or model developed to represent the submicroscopic particles in the substances being observed. Observations at the macroscopic level of changes such as colour change, or the evolution of a gas, reveal nothing about the submicroscopic behaviour of the chemicals involved.

Secondly, students perceived particles as mini-versions of the substances they compose. They often transfer the macroscopic properties of a substance to its sub-microscopic particles and thought that particles possess the same properties as the materials they compose. Item A4 would be correct conception if the statement was `chlorine gas is greenish-yellow', while item A9 should read `copper metal is reddish brown'. Such findings are not unexpected as they are consistent with previous researches where students believed that an atom of copper is malleable (Ben-Zvi, Eylon, & Silberstein, 1986) and sulphur atoms are yellow (Anderson, 1990; Garnett, Garnett, and Hackling, 1995).

For the content domain of *chemical symbols*, students found items A1 and A5 problematic. In item A1, 61.58% of the subjects believed that H_2 and O_2 are chemical symbols of the elements hydrogen and oxygen respectively whereas in item A5, 70.79% of the subjects believed that the symbol for chlorine in chlorine gas is `Cl_2'. These students were confused between chemical symbols and chemical formulae, and probably believe that only compounds have formula.

In the content domain of *chemical formulae*, items A11, A20 appear very challenging. In item A11, 74.47% of the subjects believed that in the water molecule (H_2O), a hydrogen molecule, H_2, is bonded to an oxygen atom, O. They seem to literally interpret the formula. This finding concurs with that of Ben-Zvi et al. (1987) who found evidence that some students interpret the formula H_2O as though an oxygen atom is attached to a H_2 molecule. In item A20, 83.16% of the subject believed that $C_6H_{12}O_6$ is glucose. They were not aware $C_6H_{12}O_6$ actually represents the composition of a glucose molecule. This is due to confusion between the symbolic and the macroscopic levels.

As for the content domain of *chemical equations*, 63.16% of the subjects regarded chemical equation as a representation of a chemical reaction using chemical formula only (item A12). Many students are unaware chemical equations can also be in words, models, and symbols of elements. In item A28, 55.00% believed that the plus sign (+) on both sides of a chemical equation has the same meaning. Such students do not understand the concept of a chemical equation.

5.3.3 Section Summary

The high percentage of alternative conceptions of students' basic chemical concepts (Section 5.3.1) and chemical representations (Section 5.3.2) support the contention that alternative conceptions of basic chemical concepts and chemical representations are indeed widespread among beginning chemistry learners at school, perhaps even in colleges and universities. Such conceptions are often resistant to instruction because conceptions are usually firmly entrenched in students' mind as coherent yet mistaken conceptual structures.

5.4 Difficulties in Interpreting and Using Chemical Representations

Section 5.4 examines the difficulties demonstrated by Form four science students when interpreting and using chemical representations. The difficulties were analysed in terms of categories of representational competence defined in this study. These are: (i) The ability to interpret meanings of chemical representations (RC1), (ii) the ability to translate between different representations at the same level (RC2), (iii) the ability to translate between different representations across levels (RC3), (iv) the ability to use representations to generate explanations (RC4), and (v) the ability to make connections between representations and concepts (RC5).

In this section, Table 5.18 provides a summary of correct responses for items in the Test on Representational Competence (TRC). Table 5.19 shows students' responses to Part A of the TRC, while Table 5.20 presents percent mean difficulty by category of representational competence.

Table 5.18
Correct responses for items in the TRC (n=384)

Item No.	Representational competence (by category)	Correct responses		% with difficulty
		Frequency	%	
A1	RC1	195	50.78	49.22
A2	RC2	303	78.91	21.09
A3	RC1	286	74.48	25.52
A4	RC2	244	63.54	36.46
A5	RC2	285	74.22	25.78
A6	RC5	150	39.06	**60.94**
A7	RC5	130	33.85	**66.15**
A8	RC1	307	79.95	20.05
A9	RC5	187	48.70	**51.30**
A10	RC5	180	46.88	**53.12**
A11	RC5	142	36.98	**63.02**
A12	RC3	131	34.11	**65.89**
A13	RC5	287	74.74	25.26
A14	RC3	133	34.64	**65.36**
A15	RC2	246	64.06	35.94
A16	RC2	234	60.94	39.06
A17	RC2	251	65.36	34.64
A18	RC3	163	42.45	**57.55**
A19	RC3	52	13.54	**86.46**
A20	RC2	279	72.66	27.34
A21	RC2	199	51.82	48.18
A22	RC3	43	11.20	**88.80**
A23	RC3	180	46.88	**53.12**
A24	RC5	209	54.43	45.57
A25	RC3	124	32.29	**67.71**
B1a	RC2	248	64.58	35.42
B1b	RC5	219	57.03	42.97
B2a	RC4	101	26.30	**73.70**
B2b	RC4	40	10.42	**89.58**
B3a	RC4	217	56.51	43.49
B3b	RC4	205	53.39	46.61
B3c	RC4	137	35.68	**64.32**
B4	RC4	24	6.25	**93.75**
B5i	RC1	71	18.49	**81.51**
B5ii	RC1	26	6.77	**93.23**
B5iii	RC1	28	7.29	**92.71**
B6a	RC1	33	8.59	**91.41**
B6b	RC1	70	18.23	**81.77**
B7a	RC3	65	16.93	**83.07**
B7b	RC4	16	4.17	**95.83**

Note: RC1= The ability to interpret meanings of chemical representations.
RC2= The ability to translate between different representations at the same level.
RC3= The ability to translate between different representations across levels.
RC4= The ability to use representations to generate explanations.
RC5= The ability to make connections between representations and concepts.

Table 5.18 shows 23 of the 40 items have percent difficulty exceeding 50%. Percent difficulty ranges from 21.09% (item A2) to 95.83% (item B7b).

Table 5.19
Students' responses to items in Part A of the TRC

Item No.	Frequency (n) and Percentages (%) of Responses									
	A		B		C		D		Omit	
	n	%	n	%	n	%	n	%	n	%
A1	49	12.76	**195**	**50.78**	72	18.75	62	16.15	4	1.04
A2	**303**	**78.91**	42	10.94	29	7.55	6	1.56	1	0.26
A3	**286**	**74.48**	36	9.38	32	8.33	28	7.29	0	0.00
A4	**244**	**63.54**	69	17.97	36	9.38	30	7.81	3	0.78
A5	15	3.91	35	9.11	**285**	**74.22**	47	12.24	0	0.00
A6	76	19.79	81	21.09	70	18.23	**150**	**39.06**	5	1.30
A7	57	14.84	38	9.90	156	40.63	**130**	**33.85**	1	0.26
A8	12	3.13	21	5.47	43	11.20	**307**	**79.95**	0	0.00
A9	33	8.59	151	39.32	**187**	**48.70**	10	2.60	1	0.26
A10	143	37.24	18	4.69	**180**	**46.88**	39	10.16	0	0.00
A11	27	7.03	**142**	**36.98**	81	21.09	130	33.85	1	0.26
A12	94	24.48	111	28.91	**131**	**34.11**	37	9.64	8	2.08
A13	**287**	**74.74**	25	6.51	49	12.76	19	4.95	2	0.52
A14	72	18.75	88	22.92	**133**	**34.64**	79	20.57	9	2.34
A15	50	13.02	**246**	**64.06**	51	13.28	31	8.07	2	0.52
A16	56	14.58	**234**	**60.94**	42	10.94	43	11.20	2	0.52
A17	34	8.85	38	9.90	**56**	**14.58**	251	65.36	1	0.26
A18	**163**	**42.45**	124	32.29	53	13.80	37	9.64	3	0.78
A19	52	13.54	**52**	**13.54**	247	64.32	27	7.03	1	0.26
A20	**279**	**72.66**	31	8.07	32	8.33	37	9.64	2	0.52
A21	47	12.24	53	13.80	78	20.31	**199**	**51.82**	1	0.26
A22	212	55.21	85	22.14	37	9.64	**43**	**11.20**	2	0.52
A23	84	21.88	**180**	**46.88**	44	11.46	70	18.23	1	0.26
A24	48	12.50	81	21.09	42	10.94	**209**	**54.43**	0	0.00
A25	100	26.04	84	21.88	**124**	**32.29**	68	17.71	4	1.04

Note: Key in bold face

Table 5.20
Percent mean difficulty by category of representational competence

Representational Competence (by category)	Item No.	% difficulty	
1. The ability to interpret meanings of chemical representations.	A1	49.22	
	A3	25.52	
	A8	20.05	
	A18	**57.55**	
	B5i	**81.51**	
	B5ii	**93.23**	
	B5iii	**92.71**	
	B6a	**91.41**	
	B6b	**81.77**	
			65.89*
2. The ability to translate between different representations at the same level.	A2	21.09	
	A4	36.46	
	A5	25.78	
	A15	35.94	
	A16	39.06	
	A17	34.64	
	A20	27.34	
	B1a	35.42	
			31.97*
3. The ability to translate between different representations across levels.	A12	**65.89**	
	A14	**65.36**	
	A19	**86.46**	
	A21	48.18	
	A22	**88.80**	
	A23	**53.12**	
	A25	**67.71**	
	B7a	**83.07**	
			78.83*
4. The ability to use representations to generate explanations.	B2a	**73.70**	
	B2b	**89.58**	
	B3a	43.49	
	B3b	46.61	
	B3c	**64.32**	
	B4	**93.75**	
	B7b	**95.83**	
			72.47*
5. The ability to make connections between representations and concepts.	A6	**60.94**	
	A7	**66.15**	
	A9	**51.30**	
	A10	**53.12**	
	A11	**63.02**	
	A13	25.26	
	A24	45.57	
	B1b	42.97	
			51.04*

* *denotes percent mean*

Table 5.20 displays the percent mean difficulty by category of representational competence.

At a glance, it could be seen that the category with the highest percent mean difficulty (78.83%) is RC3 - the ability to translate between different representations across levels. Percent difficulty for 7 out of the 8 items within this category exceed 50%, even for items in Part A which are multiple-choice questions. For 3 of the items (A19, A22 and B7a), percent difficulty is as high as 86.46%, 88.80%, and 83.07%, respectively.

The category with the lowest percent mean difficulty (31.97%) is RC2 - the ability to translate between different representations at the same level. Percent difficulty of all the 8 items within that category fall below 50%, even for items in Part B which is of short answer format (B1a).

The other three categories of representational competence also have percent mean difficulty exceeding 50%. These are: (i) RC1 - the ability to interpret meanings of chemical representations (65.89%), (ii) RC4 - the ability to use representations to generate explanations (72.47%), and (iii) RC5 - the ability to make connections between representations and concepts (51.04%).

Comparing the percent mean difficulty, it could be inferred that the subjects of this study had the most difficulty translating between different representations across levels (RC3). From Table 5.20, the 3 items A19, A22, and B7a have very high percent difficulty. A look at the TRC (*Appendix 15a*) shows all three items involve molecular representations of balanced equations by particulate drawings. While items A19 and A22 require students to translate from the molecular level to the symbolic level, students need to do the reverse in item B7a – translate from symbolic to molecular representation. The high percent difficulty suggests students indeed have most difficulty translating a particulate drawing into a balanced chemical equation or vice versa. That is: translating from molecular or submicroscopic representation to symbolic representation and vice versa. It could also be seen that for students having difficulty translating a particulate drawing into a balanced equation, the most common error was that of including unreacted chemical species in the balanced equation. The percentages of students with this error for items A19 and A22 were 64.32% and 86.99% respectively. Please refer to students' response pattern (Table 5.19) and the TRC (*Appendix 15a*). This finding concurred with that of Sanger (2005) and Sim (2006). The only item (item A21) in this category (RC3) with percent difficulty less than 50% (40.18%) involves translation from the symbolic level to the macroscopic level. Hence, it is reasonable to infer that students find translation between representations across levels (RC3) to be the toughest, in particular translations involving the molecular level. The fact that the mean percent difficulty for the three levels of representation of matter is the highest among all five content domains of the TCR (Table 5.16) supports this finding. This is logical as students who have poor understanding of the three levels of representation of matter and the interconnections between the levels (see Tables 5.16 and 5.17 in Section 5.3.2), would most likely encounter difficulty translating across the levels, in particular translations involving the molecular level.

If translation between representations is problematic for novice students, the findings that the ability to translate between representations at the same level (RC2) registers the lowest percent mean difficulty might appear surprising. However, examination of the items in the TRC (*Appendix 15a*) shows all the eight items within this category involve translating between different representations at the symbolic level only. Symbolic representations are extensively used in chemistry text books and reference books. Besides, in most Malaysian classrooms, teaching and learning chemistry mostly occur at the symbolic levels where chemical symbols, chemical formulae, as well as chemical equations practically become the alphabets, words and sentences in the chemistry language. This is particularly true for Chapter three of the Form Four Chemistry Curriculum. In addition, items involving the symbolic level frequently appear in textbook and examination papers, and hence more familiar among the students. In fact, items like A2 and A5 are well-practised items. This is reflected by the relatively low percent difficulty of these two items (see Table 5.20).

The percent mean difficulty (65.89%) for RC1 - the ability to interpret meanings of chemical representations is unexpectedly high. However, the fact that the percent mean difficulty for items within this category in Part A is only 38.14% suggests that the high percentage is probably due to students' inability to respond to items in Part B which required them to write the answer(s) instead of just choosing an option.

RC4 – the ability to use representations to generate explanations, records a high percent mean difficulty, the second highest after RC3. This is considered a difficult category of representational competence because students not only must know the relevant representations involved, they must also be able to use the appropriate representation to generate explanation. The fact that items B3a and B3b register percent difficulty of below 50% could be due to the fact that `atom' and `molecule' are the most fundamental concepts students are very familiar with, and that representations of `atom' and `molecule' appear in almost every chemistry text book. However, item B7b in this category, which is uncommon among the students, has the highest percent difficulty among all the items in the TRC (95.83%).

RC5 – the ability to make connections between representations and concepts, also registers percent mean difficulty exceeding 50%, even for items in Part A. This is not surprising as earlier findings Section 5.4 of this study such as the low overall levels of understanding of basic chemical concepts (45.60%) as well as the relatively high percentage of alternative conception of many basic chemical concepts (see Tables 5.12 and 5.14), reflects poor understanding of basic chemical concepts among this sample of students. Without a sound understanding of chemical concepts, making connections between representations and concepts is indeed a difficult task. The relatively low percent difficulty for item A13 appears contradictory. However, a look at the item in the TRC (*Appendix 15a*) shows similar items often appear in text book and examinations, and hence familiar to students. Such questions are also often taught in class and become well practised item among students.

Section Summary

The subjects of this study encountered the most difficulty translating between different representations across levels (78.83%), and the least difficulty translating between different representations at the same level (31.97%). See Table 5.20.

5.5 A Comparison of Form four Students of High, Medium, and Low Overall Levels of Representational Competence, in their Representations of Basic Chemical Concepts

This section describes Form four students' representation of basic chemical concepts. The description only provides a cross section as only nine subjects from the sample were interviewed. However, as the nine subjects (three each from high, medium, and low overall levels of representational competence) makes up a purposive and representative sample, it is hoped that the findings could add depth and bring further insights into Form four students' representation of basic chemical concepts. Section 5.5.1 gives an account of students' conceptions of chemical representations while Section 5.5.2 provides an account of students' representational competence. In each of these sub-sections, comparisons among the three groups of respondents were made. Similarities and differences among Form four students of high, medium, and low overall levels of representational competence, in their representations of basic chemical concepts were noted.

5.5.1 Students' conceptions of chemical representations

Conceptions of chemical representations for the nine selected participants shall be reported in the following sub-sections.

5.5.1.1 Recall without any specific prompts

All the nine participants were unfamiliar with the term "chemical representations". However, participants from the High group could manage to give correct examples of chemical representations, participants from the Medium group gave some examples but show much confusion while those from the Low group totally had no idea what chemical representations are.

The Low group

Participants from this group had no idea what chemical representations are and could not give any example, either orally, in writing or in drawing. The 2nd participant (L2) had never seen or heard the term before and was totally blank and surprised to hear such a term. The 3rd participant (L3) said he had seen the term but did not seem to know anything about chemical representations either. He tried to give some examples but none was correct. For example: he thought compounds and mole are chemical representations but drew something that looks like a molecule (Figure 5.3).

Figure 5.3: L3a

L3 was probably confused between compound and molecule, or between mole and molecule, or had no knowledge of either concept. Excerpts from the interview transcripts illustrate their conceptions of chemical representations:

I: [Showing the term `CHEMICAL REPRESENTATIONS' on a piece of paper to the participant]. What do you know or understand about chemical representations?
L1: [No response].
I: Have you seen the words `Chemical Representations'? You can just tell me what you know about chemical representations, or you can also use pictures or diagrams to describe or to explain what you know about chemical representations. [Pieces of plain paper were given to the participant]
L1: [Pause]. I forgot.
I: Can you give any example of chemical representation?
L1: I don't know.

I: What do you know or understand about chemical representations?
L2: [No response].
I: You never hear this term before?
L2: Never.
I: Can you give any example of chemical representation?
L2: Representations? [Participant appeared blank and surprised to hear that]
I: Can you give some examples?
L2: Forget already. [Pause] Like what ah???
I: Have you seen this term `CHEMICAL REPRESENTATIONS'? [Showing the term `CHEMICAL REPRESENTATIONS' on a piece of paper to the participant again].
L2: No, never see.

I: Have you seen the words `Chemical Representations'?
L3: Yes.
I: What do you know or understand about chemical representations?
L3: [Pause]…like compounds, something like mole…
I: You can just tell me what you know about chemical representations, or you can also use pictures or diagrams to describe or to explain what you know about chemical representations.
L3: [Pause]. Like compounds, like that… [Drawing something that looks like a molecule] Figure 5.3.
I: Do you want to label or say something about the drawing?
L3: No.
I: Anything else that you've heard, seen, or written, etc, which you think are chemical representations?
L3: [Long pause]. Nothing. No more.

The Medium group

Participants form this group were also unfamiliar with the term “chemical representations”. M1 was uncertain what chemical representations really are. He could give examples but showed much confusion between basic chemical concepts. For example: saying chemical formula but wrote a chemical equation (Figure 5.4). He also mentioned `electron number’ of an atom (Figure 5.4). M2 did not know the term and could only manage to give some examples of chemical representations when prompted (see Figure 5.5). M3 was unfamiliar with the term and tend to link chemical representations with chemical reactions. Excerpts from the interview transcripts provide evidence of their conceptions:

I: What do you know or understand about chemical representations or representations in chemistry? [Showing the words `chemical representations’ written on a piece of paper]
M1: Chemical representations? What ah?
I: [Repeat question to the participant]
M1: Chemical representations show the… I think, chemical formula of an element…
I: Only chemical formula? Anything else?
M1: [Silence…]
I: You can also use pictures or diagrams or words to describe or to explain what you know about chemical representations. [Pieces of plain paper were given to the participant]
M1: Looking at the plain paper and thinking…
I: Can you give some examples of chemical representations or representations in chemistry? You can show your answers by either writing or drawing.
M1: [Nothing written or drawn on the plain paper]
I: [Interviewer repeated the question above]
M1: [Participant began writing on the plain paper and read out at the same time]. See Figure 5.4.
Chemical formula is like this: $C(s) + O_2(g) \rightarrow CO_2(g)$

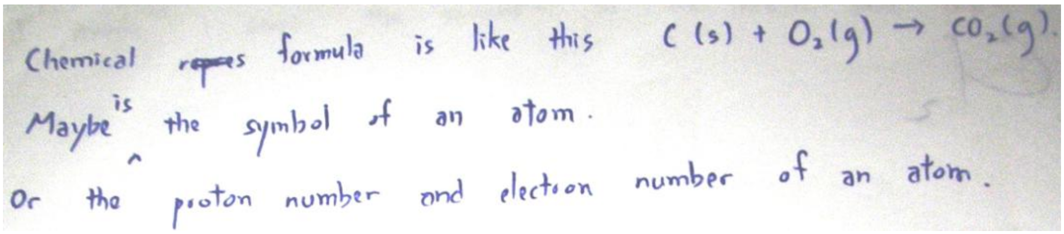


Figure 5.4: M1a

I: [Pointing at the above chemical equation written by the participant on the paper]. Is this chemical formula?
M1: [Silent and appearing confused]
I: Any other things that you consider are chemical representations?
M1: [Continue thinking and writing then read out]. Maybe is the symbol of an atom, or the proton number and electron number of an atom. See Figure 5.4.
I: What do you know or understand about chemical representations?

M2: [Long silence, then muttering something] chemical representations?
I: You can use pictures or diagrams or words to describe or to explain what you know about chemical representations.
M2: [Looking at the plain paper and thinking]
I: If you find it difficult to explain in words, you can draw.
M2: [Silence again]
I: Can you give some examples of chemical representations or representations in chemistry?
M2: [No response and nothing written or drawn on the plain paper also]
I: Beginning Form 4, you learn about chemical representations.
M2: Forgot already. [Pause, then trying to draw something] See Figure 5.5.
I: Any more examples that you would like to show?
M2: [Trying hard to draw some more]. See Figure 5.5.
I: Any other things that you want to show?
M2: No more.

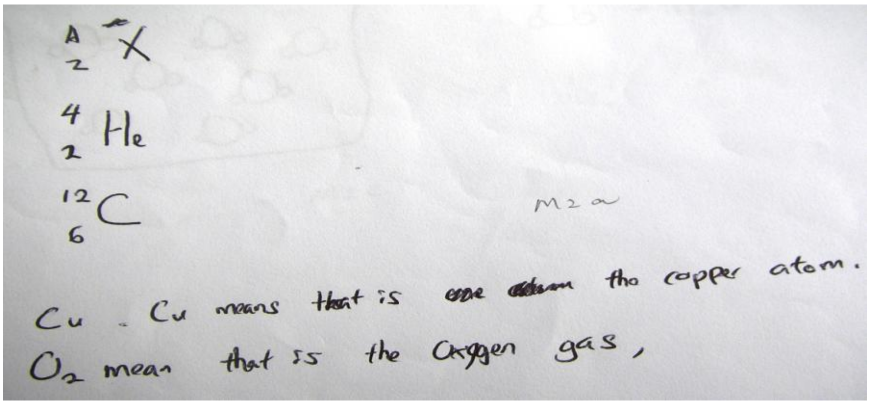


Figure 5.5: M2a

I: What do you know or understand about chemical representations or representations in chemistry?
M3: Chemical representations? Eh…eh…
I: [Repeat question to the participant]
M3: I think, chemical reactions after … eh…
M3: [Silence…]
I: You can also use pictures or diagrams or words to describe or to explain what you know about chemical representations. [Pieces of plain paper were given to the participant]
M3: [A very long pause. Participant appeared to be thinking hard]
I: Can you give some examples of chemical representations or representations in chemistry? You can either say it in words or you can draw something which you think are examples of chemical representations.
M3: [Another long pause]
I: [Interviewer repeated the question above]
M3: [Participant began writing on the plain paper. Two separate sentences were written]. See Figure 5.6.

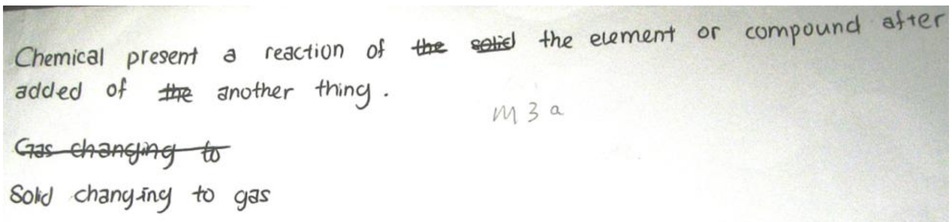


Figure 5.6: M3a

The High group

Participants from the High group were just as unfamiliar with the term "chemical representations". They tended to relate the term with symbols used in chemistry (H1), uncertain what chemical representations really are and needed prompting to get answers (H3). The 2nd participant (H2) also could not explain what chemical representations were although he was able to give correct examples of chemical representations orally and in writing, but did not draw anything. Excerpts from the interview transcripts support these findings:

I: What do you know or understand about chemical representations or representations in chemistry?
H1: Chemical representations?
I: You can also use pictures or diagrams or words to describe or to explain what you know about chemical representations. [Pieces of plain paper were given to the participant]
H1: Any symbol used in chemistry will do?
I: You can say or write or draw anything that according to your understanding is chemical representation. If you find it difficult to describe in words, you can give some examples and show your answers by either writing or drawing.
H1: [Participant began writing on the plain paper and read out at the same time]. See Figure 5.7. Symbols like this means X is in the gaseous state, structural formula of organic compound, …

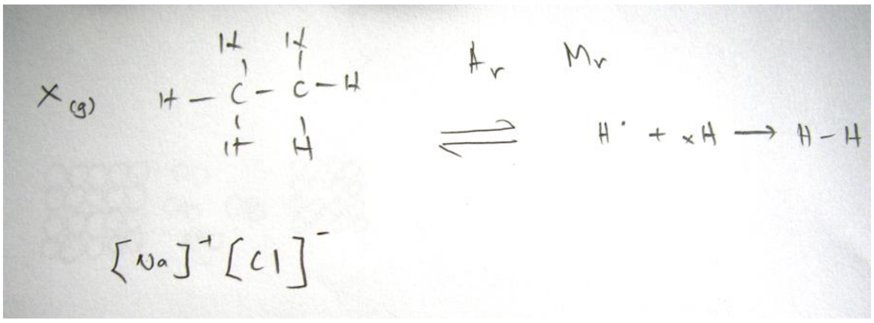


Figure 5.7: H1a

I: Anything else that you would like to add to the list?
H1: [Continue writing and reading out]. M_r is relative molecular mass, A_r is relative atomic mass,
I: Ok.
H1: [Writing and drawing some more examples and explaining at the same time. This symbol means covalent bond.
I: Anything else?
H1: Ionic bond [continue writing and drawing]
I: How about symbols of elements, chemical formulae, chemical equations, are they chemical representations?
H1: Yes.

I: What do you know or understand about chemical representations or representations in chemistry?
H2: Hmm… chemical representations? In my opinion, they are examples like letters representing elements like those in the Periodic Table, and numbers to represent oxidation number, and so on, also symbols to represent some of the elements.
I: You can also write or draw anything which to you are chemical representations.

H2: [Taking quite a while writing but no drawing appears on the paper]. See Figure 5.8.
I: Do you want to draw anything?
H2: I don't think so.

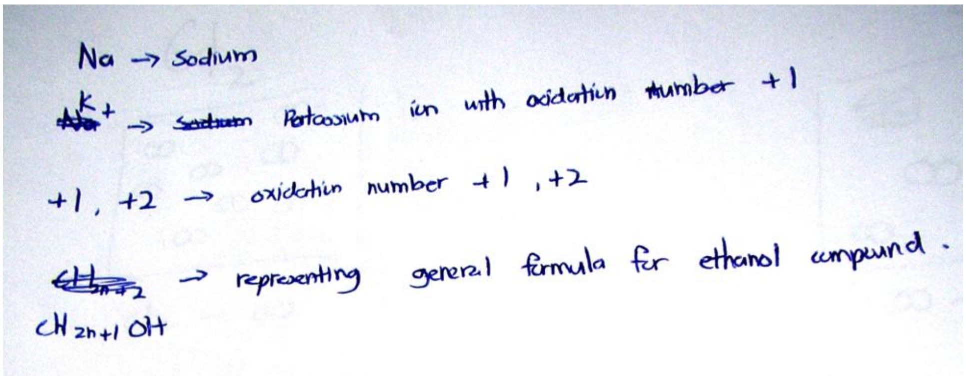


Figure 5.8: H2a

I: What do you know or understand about chemical representations or representations in chemistry?
H3: Interactions in chemistry, or …
I: Perhaps you can write or draw anything which to you are chemical representations. You can also give some examples of chemical representations.
H3: Like chemical equations, hmm…, everything in our life is related to chemistry, like water.
I: Any other common examples of chemical representations?
H3: Diagrams, electrons, [Participant appeared uncertain what chemical representations really are].
I: Any other examples?
H3: [Pause]
I: How about chemical formulae, chemical symbols of elements, are they chemical representations?
H3: Yes. [Participant needed prompting to get answers]

5.5.1.2 Questions based on TCR

(See items A9 and A20 of the TCR in *Appendix 11a*).

Students tend to perceive particles as mini-versions of the substances they compose. They often transfer the macroscopic properties of a substance to its submicroscopic particles and thought that particles possess the same properties as the materials they compose. Item A9 should read `copper metal is reddish brown'. Such findings are not unexpected as they are consistent with previous researches where students believed that an atom of copper is malleable ((Ben-Zvi, Eylon, & Silberstein, 1986). In item A20, 83.16% of the subject in this study believed that $C_6H_{12}O_6$ is glucose (macroscopic). They were unaware $C_6H_{12}O_6$ (symbolic) actually represents the composition of a glucose molecule (microscopic). This is due to limited understanding of the three levels of representation of matter, as well as confusion between the three levels.

The Low group

Participants in this group had little knowledge of basic chemical concepts and were unfamiliar with common substances (macroscopic). L1 just responded that copper atom is not reddish brown but did not know why and could not explain. L2 seemed to know that copper and copper atoms are different but thought that when copper atoms are mixed, then get copper. L3 thought that copper atoms and copper represents the same thing, but when asked further became unsure and confused. L3 even thought that the copper strip is magnesium ribbon. Excerpts from the interview transcripts provided evidence for the findings:

I: [Showing a copy of the Test on Chemical Representations, TCR, see *Appendix 11a*, to the participant]. Do you remember doing this test?
L1: [Flipping through the test paper]. Yes.
I: Let's look at the test paper. Do you think that statement A9 is true or false?
L1: False.
I: Why do you think that the statement is false?
L1: [Participant was silent and appeared to be thinking]. I think copper atom is not reddish-brown.
I: So, it is …
L1: [Pause]. I don't know.

I: Let's look at the test paper. Is the statement A9 true or false?
L2: Copper atoms? [Pause] True.
I: Why do you think that the statement is true?
L2: I've seen before.
I: What have you seen?
L2: Copper.
I: Have you seen copper atoms?
L2: No.
I: Do you think copper and copper atoms mean the same thing?
L2: No, different.
I: What do you think is the difference?
L2: The atoms.
I: What do you mean when you said `the atoms'?
L2: The copper is mixed already.

I: Do you think that statement No. 9 is true or false?
L3: [Answering spontaneously]. True.
I: You think that the statement is true?
L3: Yes.
I: Why do you think that the statement is true?
L3: Ha… [Pause] Don't know how to explain.
I: Can you just say something about the statement?
L3: Copper atoms are like brown colour.

I: Have you seen copper atoms?
L3: Yes.
I: Do you think copper atoms and copper metal is the same thing?
L3: [Pause]. Maybe
I: [Showing a strip of copper to the participant]. Have you seen this before?
L3: Yes.
I: What is this?
L3: Magnesium ribbon.
I: [Surprised at the answer]. Magnesium ribbon?
L3: Copper ribbon.
I: Ok, copper. Is it copper or copper atom?
L3: Copper.
I: Is copper and copper atom the same thing?
L3: Don't know. Not sure.

The Medium group

M1 believed that copper atoms are reddish brown, showed confusion between copper atom and the element copper, seemed to know that copper atom is part of copper element but did not know how they were related, could not distinguish between copper atom (a submicroscopic term) and copper element (a macroscopic term). M2 also believed that copper atoms are reddish brown and that copper atom and copper are the same, although when prompted said that copper atom is only one atom and copper is many atoms. M3 did not perceive copper atoms as reddish brown but when questioned further appeared unsure and confused. Excerpts from the interview transcripts support the findings:

I: [Showing a copy of the TCR to the participant]. Do you think that statement A9 is true or false?
M1: True.
I: Why do you think copper atoms are reddish brown?
M1: [Started to recall an experiment on the displacement of copper metal from its salt solution] Teacher, last time we did an experiment before. When we put a piece of copper into a blue solution, a reddish brown solid was formed. Teacher you said the solid was copper.
I: Is copper atom the same as the element copper?
M1: Copper atom is part of copper element. Copper element is …
I: What do you mean by `copper atom is part of copper element'?
M1: [No response and looking very confused]

I: Let's look at the test paper. Do you think that statement A9 is true or false?
M2: [Silence]
I: [Repeat question]
M2: Reddish brown is what colour?
I: Something like chocolate colour.
M2: True.

I: Why do you think copper atoms are reddish brown?
M2: I have seen this colour before.
I: You have seen copper? Do you think copper atom and copper are the same?
M2: Copper atom is only one atom. Copper is many atoms.
I: So do you think they (copper atom and copper) are the same?
M2: Yes. They are the same.

I: Do you think statement A9 is a true or a false statement?
M3: False.
I: Why do you think the statement is false?
M3: [Thinking … and muttering something after sometime]. Dark brown??
I: You know the statement is not true but you cannot explain?
M3: Yes ... [Participant appearing unsure and confused]

The High group

When referred to statement A9, only the 1st participant (H1) could distinguish clearly between copper atom and the element copper. He recognised the existence of the submicroscopic and macroscopic worlds and could relate between the two levels. H2 believed that copper atoms are brown in colour because copper element is brown in colour. The participant extended macroscopic properties of a substance to its submicroscopic entity, and appeared puzzled when told that statement no. 9 is false. H3 also believed that copper atoms and the element copper mean the same thing. He appeared surprised when told that the statement is false.

The High group was also tested on items 20 and 23, both concerning molecular formula. On statement No. 20, both H1 and H2 knew that the statement was false but gave wrong explanation. H3 also knew the statement was false but did not know why. None of the participant was aware that $C_6H_{12}O_6$ is just a representation of the glucose molecule and that it is in fact the molecular formula of glucose and not glucose itself.

I: [Showing a copy of the Test on Chemical Representations, TCR to the participant]. Now look at the test paper. Do you think statement A9 is true or false?
H1: False.
I: Why do you think that the statement is false?
H1: I think copper atom itself has no colour but when a lot of atoms make up the element copper, it is reddish brown.

I: [Pointing to Item A9 and asking]. Is this statement true or false?
H2: True.
I: Why do you think that the statement is true?
H2: Because copper element is brown in colour.
I: But the statement is about copper atom.
H2: Copper element contains copper atoms. So, copper atom is part of the copper element.
I: Is this your interpretation?
H2: Yes.
I: In fact, the statement is false.
H2: [Appeared puzzled]

I: Is statement A9 a true or a false statement?
H3: False.
I: Why do you think that the statement is false?
H3: [Participant changed his answer from false to true after a short pause]. … I think the statement is true. The ions are blue.
I: Why are you talking about copper ions? The statement was about copper atoms, not ions. Can you explain why you believe copper atoms are reddish brown?
H3: For example during electrolysis, copper are deposited at the cathode. It is reddish brown.
I: Is there any difference between copper atoms and the element copper?
H3: Copper is the element.
I: So copper atoms and the element copper mean the same thing to you?
H3: Yes.
I: Actually, statement A9 is a false statement.
H3: [Participant appeared surprised at the answer].

I: Now look at statement A20. Is it a true or false statement?
H1: False.
I: Why do you think it is a false statement?
H1: It should be hexose generally. Glucose is only a subset of hexose.
I: Would you like to correct the statement to make it a true statement?
H1: [No response]

I: Is statement A20 a true or false statement?
H2: False.
I: How can you correct the statement to make it a true statement?
H2: $C_6H_{12}O_6$ is just a general formula of glucose.
I: General formula? So, to you what is $C_6H_{12}O_6$?
H2: [Participant appeared confused]
I: In fact, $C_6H_{12}O_6$ is just a representation of the glucose molecule. It is the molecular formula of glucose and not glucose itself.
H2: [Participant seemed to agree]

I: Let's look at statement A20. Is it a true or false statement?
H3: False.
I: How about statement A23?
H3: [pause and thinking]. I think it is true.
I: So statement A20 is false but statement A23 is true. Can you tell me why statement A20 is false?
H3: [Not responding].

5.5.1.3 Symbolic representations

Question 1 – The symbol `Cu'

To interpret the symbol `Cu', participants need to know that the symbol `Cu' has both a macroscopic and a microscopic interpretation. Hence, the symbol `Cu' can represent:

(i) the element copper (qualitative, macroscopic), or

(ii) 1 mole of copper (quantitative, macroscopic), or

(iii) 64g of copper (quantitative, macroscopic), or

(iv) 1 atom of copper (quantitative, microscopic), or

(v) N_A atoms of copper (quantitative, microscopic).

The most common interpretation among the participants is (i), which is the chemical symbol of the element copper. It could be inferred that the participants only looked at the macroscopic and qualitative aspect of symbolic representations.

<u>The Low group</u>

The Low group does not even know or is familiar with chemical symbols of common elements like copper. All the three participants had seen the symbol `Cu' before but did not know the meaning of the symbol. Both L1 and L2 thought that `Cu' means carbon. L2 appeared surprised when told his answer was wrong. L3 thought that the symbol `Cu' means two different things. He said `C' means carbon or copper but did not know what `u' is. He was not aware `Cu' is only one symbol, not two. Excerpts from the interview transcripts provide further insights:

I: Let's look at some symbolic representations. [Showing the symbol `Cu' written on a piece of paper to the participant] What does the symbol `Cu' mean to you?
L1: [Pause]
I: Have you seen this symbol before?
L1: Yes.
I: So, what is the meaning of `Cu'?
L1: [Silence]

I: Have you written or used this symbol before?
L1: Yes.
I: What do you think this symbol mean?
L1: Carbon.
I: [Pointing to the symbol `Cu' written on the paper].  It is capital letter `C', small letter `u'.
L1: Maybe is copper.

I: What does the symbol `Cu' mean to you?
L2: [Pause]
I: Have you seen this symbol before?
L2: Yes.
I: So, what do you think is the meaning of `Cu'?
L2: [Another long pause, then suddenly uttered a phrase]. Is it carbon atom?
I: No.
L2: [Participant appeared surprised his answer is wrong]
I: So you still think this symbol means carbon atom?
L2: Yes.

I: Have you seen the symbol `Cu' before?
L3: Yes.
I: What does the symbol `Cu' mean to you?
L3: Carbon or copper.
I: Carbon?
L3: `C' means carbon or copper.  `u'?? I don't know.
I: So to you the symbol `Cu' means two different things?
L3: Yes.

The Medium group

Participants knew about chemical symbols of elements but not very familiar. M1 said `Cu' means copper atom or the element copper.  M2 thought that `Cu' means the copper atom. M3 knew that `Cu' is symbol of element but could not remember which element. See excerpts from the interview transcripts:

I: What does the symbol `Cu' mean to you?
M1: Copper atom or copper.
I: Copper?
M1: I mean copper element.

I: What does the symbol `Cu' mean to you?
M2: Mean the copper atom.
I: Any other meaning?
M2: [Long pause]. …no [apparently uncertain]
I: Perhaps you can write or draw…
M2: [Trying to write something, but nothing appeared on the paper]

I: What is the meaning of the symbol `Cu'?
M3: [Pause]
I: You can say anything that you think this symbol means to you.
M3: Symbol of element.
I: `Cu' is the symbol of which element?
M3: [Long pause. Participant was trying hard to recall]. I can't remember.
I: Do you think the symbol has any other meaning other than symbol of element?
M3: [Silence]

The High group

Although participants were very familiar with chemical symbols of common elements, all tended to associate or link the symbol `Cu' to either copper atom or the element copper (qualitative aspect only). H1 only thought that the symbol `Cu' means copper atom although he agreed that it also means one copper atom or one mole of copper atoms, but admitted he did not think of that. H2 said the symbol `Cu' means the element copper while H3 said the symbol `Cu' represents the element copper. When questioned further, H3 said it also means copper atom and agreed that the symbol also can represent one mole of copper or an atom of copper.

I: Now, let's look at some symbolic representations. What does the symbol `Cu' mean to you?
H1: Copper atom.
I: Any other meaning?
H1: I don't think so.
I: So it only mean copper atom to you?
H1: [Not responding]
I: Does `Cu' refer to 1 Cu atom or 1 mole of Cu atom?
H1: Both also can.
I: Why didn't you mention earlier?
H1: I did not think of that.

I: What does the symbol `Cu' mean to you?
H2: Copper, the element copper.
I: Any other meaning?
H2: [Writing on the plain paper provided]. See Figure 5.9.
I: Anything else you would want to write?
H2: No more.

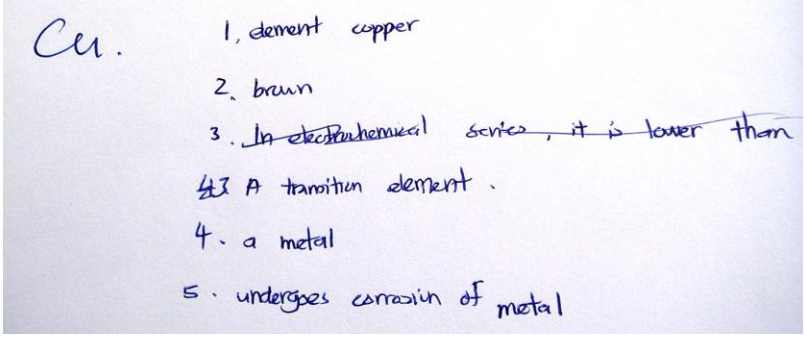


Figure 5.9: H2b

I: Now, let's look at some symbolic representations. What does the symbol `Cu' mean to you?
H3: Represents the element copper.
I: Any other meaning?
H3: The composition of copper or copper atom.

I: If I say `Cu' also represents 1 mol of copper, do you agree?
H3: Yes, 1 mol of copper.
I: Can it also represent 1 atom of copper?
H3: Yes. [Also writing something on the plain paper provided]. See Figure 5.10.

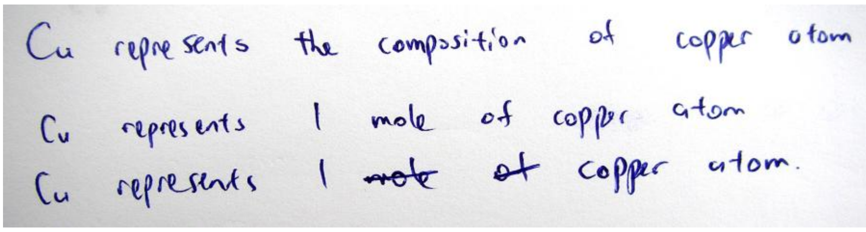


Figure 5.10: H3b

Question 2: The symbols O_2, 2O and O^{2-}

To be able to distinguish or explain the meaning of the number `2' in each of the symbols, the participants must be able to: (i) understand chemical symbols and chemical formula, and (ii) differentiate between coefficients and subscripts such as 2O and O_2, (iii) the type of particles or the three basic particles of matter (atoms, molecules, and ions), (iv) atomicity, and (v) charge of an ion.

<u>The Low group</u>

All the participants from this group had seen these three symbols, knew the number `2' in each of the symbol has different meaning but could not explain the meaning or distinguish between them. L1 seemed to have some ideas what an atom is and tried to draw to show 2O but not O_2 (Figure 5.11). L2 showed drawings of O_2 and 2O (Figures 5.12 and 5.13) but Figure 5.12 seems to show particle (molecule) of a compound. L3 showed drawings of O_2 and 2O but both the drawings were also wrong (Figures 5.14 and 5.15). From his drawings, L3 seemed to think that an atom is smaller than a molecule. All the participants had no idea what an ion is. Participants' inability to represent or explain the concepts is probably caused by their poor conceptual understanding about the particles of matter – atoms, molecules and ions.

I: [Showing three symbolic representations to the participant: O_2, 2O, O^{2-} (see Focus Card 1 – *Appendix 23*). Have you seen these symbols before?
L1: [Answering very fast]. Yes.
I: Does the number `2' in each of the representation above have the same meaning?
L1: No.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
L1: [Looking at the symbolic representations and apparently thinking]
I: What does the number `2' in O_2 mean?
L1: [Pause]. 2 of oxygen.
I: 2 of oxygen? Can you explain what you meant by `2 of oxygen'?
L1: [Pause]
I: What type of particle is O_2?
L1: Don't know.
I: Ok, now what is the meaning of the number `2' in 2O?
L1: I only remember H_2O.
I: So, what is the meaning of `2' in 2O?
L1: 2 oxygen atoms.
I: Can you use drawing to show the difference between O_2 and 2O?
L1: [Writing down the symbols O_2 and 2O, then drawing something on the plain paper provided. However, participant could not draw anything to show what O_2 looks like. The drawing only shows 2O, which is also wrong]. See Figure 5.11.

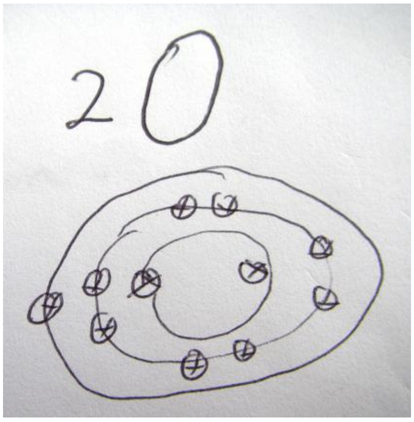


Figure 5.11: L1a

I: What about the number `2' in O^{2-}?
L1: [Not responding]
I: [Pointing to the symbol O^{2-}]. What type of particle does this symbol represent: atom, molecule or ion?
L1: Atom.
I: Why do you think it is an atom?
L1: [No response]

I: [Showing three symbolic representations to the participant: O_2, 2O, O^{2-} .Have you seen these symbols before?
L2: Yes.
I: Does the number `2' in each of the representation above have the same meaning?
L2: No.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
L2: [Looking at the symbolic representations]
I: What does the number `2' in O_2 mean?
L2: [Long pause]
I: What is the meaning of `O'?
L2: Oxygen.
I: So, O_2 means …
L2: [No response but apparently thinking]

I: Is O_2 an atom?
L2: No.
I: Is it a molecule?
L2: Molecule? I think yes.
I: Can you draw to show how O_2 look like?
L2: No.
I: Ok, now what is the meaning of the number `2' in 2O?
L2: Don't know.
I: Can you draw to show how 2O look like?
L2: Haa.. draw again?
I: Can you write down the symbols O_2 and 2O first?
L2: [Writing down the symbols O_2 and 2O]
I: Now draw to show how O_2 look like.
L2: [Participant drawing something on the plain paper provided but the drawing shows 1 big circle and 2 smaller circles]. See Figure 5.12.
I: [Pointing at the drawing in Figure 5.12]. Can you explain what you have drawn?
L2: I only know H_2O.
I: Can you draw to show 2O?
L2: [Participant drawing shows something that looks like a molecule - 2 big, similar circles joined together]. See Figure 5.13.
I: What about the number `2' in O^{2-}?
L2: [Not responding]

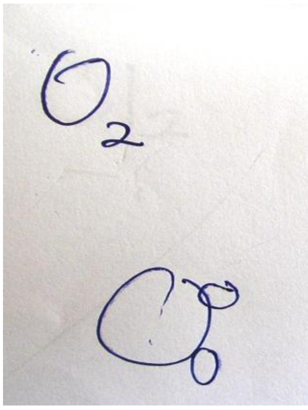


Figure 5.12: L2a

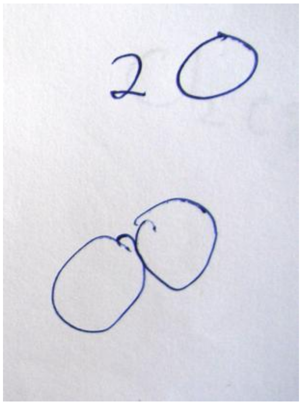


Figure 5.13: L2b

I: [Showing three symbolic representations O_2, 2O, O^{2-} to the participant]. Have you seen these symbols before?
L3: Yes.
I: Does the number `2' in each of the representation above have the same meaning?
L3: [Pause]. No.
I: What does the number `2' in O_2 mean?
L3: `2' means 2 atoms of oxygen combined to become oxygen.
I: What is the meaning of the number `2' in 2O?
L3: 2 oxygen atoms.
I: Can you use drawing to show the difference between O_2 and 2O?
L3: [Writing down the symbols O_2 and 2O on the plain paper provided].
I: Ok, now can you draw to draw how O_2 look like?
L3: [Drawing, but drawing shows something that looks like an atom, a circle]. See Figure 5.14.

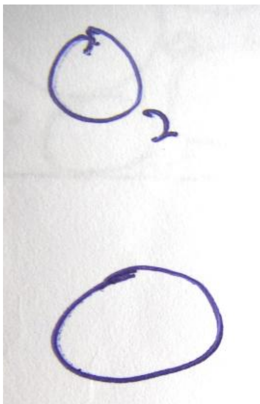


Figure 5.14: L3b

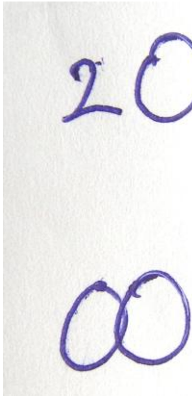


Figure 5.15: L3c

I: Just now you said 2 oxygen atoms. Why did you draw only one circle (or atom)?
L3: Two atoms combined becomes one, like that … [Pointing to the bigger circle in Figure 5.14].
I: How can you draw to show `2O'?
L3: [Drawing again, but this time the drawing shows 2 smaller circles joined together]. See Figure 5.15.
I: Why are you drawing the 2 circles together?
L3: Don't know.
I: [Pointing to the symbol O^{2-}]. What is the meaning of the number `2' in O^{2-}?
L3: Don't know.
I: [Still pointing at the symbol O^{2-}]. Does it represent an atom?
L3: No.
I: What type of particle does this symbol represent?
L3: Don't know.

<u>The Medium group</u>

Participants in this group seem to know `atoms' and `molecules', but still unsure or confused about `ions', knew the number `2' in each of the symbol has different meaning but could not explain the meaning or distinguish between them. M1 could use drawing to show the difference between O_2 and 2O (Fig. 5.16), understood the concept of `atom' and `molecule' and could represent the concepts `atom' and `molecule' correctly. He seemed to know what an ion is but still confused with the charge of ions and could not distinguish between +/- ions. M2 could not use drawing to show the difference between O_2 and 2O, but could differentiate a molecule from an atom, knew what an ion is but not clear how +/- ions are formed. M3 also seemed to know what an atom and a molecule is but was confused between the concepts `atom' and `element'. He could differentiate between O_2 and 2O by drawing but had wrong conception how O_2 molecule was formed from oxygen atoms. He had no idea what an ion is. Excerpts from the interview transcripts illustrate these findings:

I: [Showing three symbolic representations O_2, 2O, O^{2-} to the participant]. Does the number `2' in each of the representation above have the same meaning?
M1: Not the same.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
M1: [Looking at the symbolic representations and thinking]
I: What does the number `2' in O_2 mean?
M1: O is atom. O_2 shows double atom of oxygen. O_2 is empirical formula of oxygen.
I: What do you mean when you said "double atom of oxygen"?
M1: I mean 2 atoms of oxygen.
I: Ok, what about 2O?
M1: 2 oxygen atoms.
I: But you mentioned earlier O_2 also means 2 atoms of oxygen??? Can you use drawing to show the difference between O_2 and 2O?
M1: [Drawing]. See Figure 5.16.

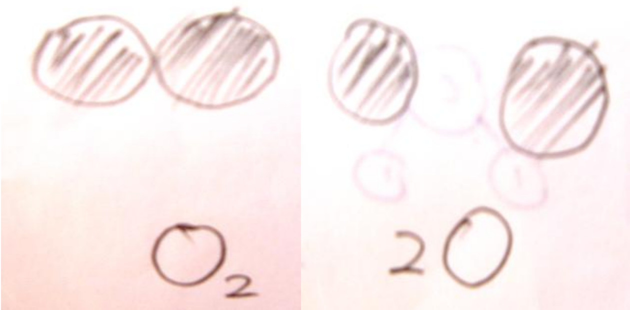


Figure 5.16: M1b

I: What about the number `2' in O^{2-}?
M1: [Not responding]
I: What type of particle is this, atom or molecule or ion?
M1: Ion.
I: Is this a positive or negative ion?
M1: Positive ion.
I: Why do you say so?
M1: Because it gave away 2 electrons.
I: So to you, this is a positive ion?
M1: Yes.

I: Does the number `2' in each of the representation above have the same meaning?
M2: No.
I: Can you explain the meaning of the number `2' in each of the representation?
M2: [Looking at the symbolic representations and thinking]
I: What does the number `2' in O_2 mean?
M2: `2' in O_2 means oxygen gas. [Long pause] … 2 molecules
I: Is O_2 a molecule or an atom?
M2: A molecule.
I: So what does `2' in O_2 mean?
M2: 2 atoms of oxygen.
I: Then, what is the meaning of `2' in `2O'?
M2: Maybe same as the 1^{st} one.
I: What do you mean by saying that?
M2: Maybe used to write, or … calculate…
I: When you see `2O', do you think of a molecule or an atom?

M2: Atom.
I: So what does `2O' mean?
M2: 2 atoms…
I: Can you be more specific? Like say "2 atoms of …"
M2: 2 atoms of oxygen.
I: What about the number `2' in O^{2-}?
M2: [Not responding]
I: Is O^{2-} an atom, a molecule or an ion?
M2: Ion.
I: What does `2' in O^{2-} mean?
M2: 2 valence electrons.
I: What do you mean by saying that?
M2: Short of 2 electrons.
I: Isn't short of electrons should have positive charge?
M2: Because at first 2.6, then becomes 2.8. So, short of 2 electrons.
I: Why not gaining 2 electrons?
M2: [Participant repeated the above answer]
I: Is it a positive or negative ion?
M2: Negative ion.

I: Does the number `2' in each of the representation above have the same meaning?
M3: No.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
M3: [Looking at the symbolic representations and thinking]
I: What does the number `2' in O_2 mean?
M3: 2 elements …
I: How about 2O?
M3: Has 2 elements but not mixed together. The first one, $O_{2,}$ is mixed together.
I: Can you draw to show the difference between the symbols O_2 and 2O?
M3: [Participant drawing an oxygen molecule and 2 oxygen atoms] see Figure 5.17.

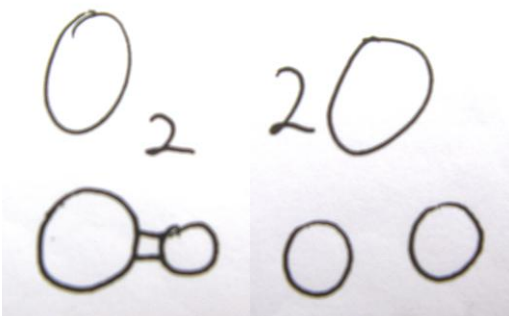


Figure 5.17: M3b

I: Ok. What about the number `2' in O^{2-}?
M3: 2 share atoms.
I: Can you draw to show me what you mean by "2 share atoms"?
M3: [Not responding]
I: [Pointing to the symbol O^{2-} and asking]. What type of particle is this, atom, molecule or ion?
M3: [Muttering something but not clear]
I: Can you repeat your answer?
M3: 2 share atoms… [Appearing unsure]
I: So, is this an atom?
M3: [Silence]
I: I give you a choice: atom, molecule, or ion?
M3: Molecule.

The High group

All the three participants could explain the meaning of the number `2' in each of the representation, could easily distinguish between `atom', `molecule', and `ion'. They had sound conceptual understanding of the fundamental particles of matter. Excerpts from the interview transcripts provide evidence of their conception:

I: [Showing three symbolic representations O_2, 2O, O^{2-} (see Focus Card 1 – *Appendix 23*) to the participant]. Does the number `2' in each of the representation above have the same meaning?
H1: No.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
H1: [Looking at the symbolic representations and responding immediately]. The subscript `2' in O_2 means 2 atoms of oxygen and the whole thing is a molecule.
I: What about 2O?
H1: `2' means 2 oxygen atoms or 2 moles of oxygen atoms.
I: What about the number `2' in O^{2-}?
H1: Oxygen exists as an ion with a negative charge of 2.

I: Does the number `2' in each of these representations have the same meaning?
H2: They are different.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
H2: O_2 means 2 oxygen atoms combined together to form an oxygen molecule; 2O means 2 atoms of oxygen; O^{2-} means oxygen having oxidation number of -2.
I: So, in terms of particle, how would you classify them?
H2: O_2 is a molecule, 2O are atoms, O^{2-} represents a negative ion.

I: Does the number `2' in each of the representation above mean the same thing to you?
H3: No.
I: Can you distinguish or explain the meaning of the number `2' in each of the representation?
H3: In O_2, the `2' means there are 2 oxygen atoms forming a molecule. 2O means there are 2 oxygen atoms.
I: How about O^{2-}?
H3: The oxygen atom receives 2 electrons to form an ion.
I: So what does the number `2' mean?
H3: The number of electrons exceeds the number of protons by 2.
I: So, in terms of the type of particles, how would you classify the 3 particles?
H3: O_2 is a molecule; 2O are atoms; O^{2-} is an ion.
I: Is O^{2-} is a positive or a negative ion?
H3: Negative ion, 2 negative charges.

Question 3 – Ball-and-stick models

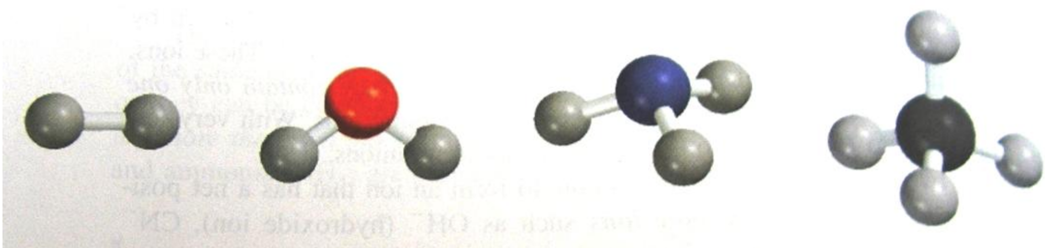


Figure 5.18: Ball-and-stick models of some simple molecules

The Low group

All the three participants had seen ball-and-stick model of the water molecule but did not know what a model is or what a ball-and-stick model represents. All of them did not know what the sticks represent. They only see the surface features of the model and had a macroscopic or concrete view of the object. L1 perceived ball-and-stick model as the real or actual substance, not a representation. He knew the balls represent atoms but did not know why the balls have different colours and/or sizes. Both L2 and L3 thought the smaller ball represents atom while the larger ball represents molecule. However, they did not know what the whole ball-and-stick model represent. L3 seemed to know the balls represent atoms but did not know why the balls have different colours and/or sizes. He also thought that water exists as atoms but when questioned further became unsure and confused.

I: [Showing the ball-and-stick models of common molecules such as hydrogen, water, ammonia and methane] (see Figure 5.18 or Focus Card 2 – *Appendix 24*).
L1: [Looking at the models with keen interest]
I: [Pointing to the ball-and-stick model of a water molecule]. Have you seen this before?
L1: Yes. It is "H-two-O" [meaning H_2O or water].
I: What do the sticks represent?
L1: [Long pause]
I: [Showing a ball-and-stick model of another molecule – methane]. What does the stick represent?
L1: [Another long pause]. Something like reaction …
I: Can you explain what you mean when you said "something like reaction"?
L1: [No response]
I: Now, what do the balls represent?
L1: Atom.
I: Good. Why do the balls have different colours and or sizes?
L1: Maybe … [Pause]. Atoms mixed together??
I: What do you mean when you said "atoms mixed together"?
L1: I can't explain. Don't know how to say…

I: [Pointing to the ball-and-stick model of a water molecule]. What do the sticks represent?
L2: [Pause]. Take it together.
I: What do you mean when you said "Take it together"?
L2: Stick together, join together.
I: Now, what do the balls represent?
L2: [Pointing at the smaller, white colour ball and said]. Atom (See Figure 5.19)
I: How about this? [Pointing at the larger, red colour ball] (See Figure 5.19)
L2: Molecule.
I: So, what does the whole thing represent? [Showing a model of the water molecule]
L2: Don't know.
I: Why do the balls have different colours and or sizes?
L2: [No response]

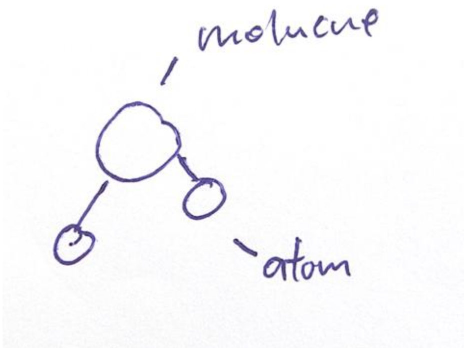


Figure 5.19: L2c

I: [Pointing to the ball-and-stick model of a water molecule]. Have you seen this before?
L3: Yes.
I: What do the sticks represent?
L3: Combine.
I: Combined?? What do you think has combined?
L3: [Pause]
I: What has combined?
L3: Two things combined becomes one.
I: Can you explain what are the `two things', and how they combine?
L3: [Pointing to the 2 smaller, white colour balls (representing 2 hydrogen atoms) and said]. These 2 combine become 1 oxygen atom. Two same atoms combined become one atom [This time pointing at the larger, red colour ball (represents an oxygen atom)]
I: [Pointing to the model of the water molecule]. Is this also an atom?
L3: Yes.
I: Does water exist as atoms?
L3: Don't know.

The Medium group

M1 knew the sticks represent the bond and the balls represent atoms. He also knew why the balls have different colours and/or sizes. M2 only knew the balls represent atoms and why the balls have different colours and/or sizes. However, he did not seem to know what the sticks (3D) or the lines (2D) represent, and had no idea what chemical bonds are. M3 did not seem to know what the sticks represent. He was uncertain what the balls represent and unsure what the whole ball-and-stick model represent as well. He seemed to know why the balls have different colours and/or sizes but could not explain. He was again confused between atom and element.

I: [Showing ball-and-stick models of common molecules such as water, ammonia and methane]. What do the sticks represent?
M1: Represent the bond.
I: What do the balls represent?
M1: The balls represent the atoms.
I: Good. Why do the balls have different colours and/or sizes?
M1: Because our world many types of atoms. Atoms are directly different from one another.
I: What do you mean when you said `atoms are directly different from one another'?
M1: They are different atoms.

I: [Show actual ball-and-stick models of common molecules such as water, ammonia and methane]
M2: [Looking at the models with keen interest]
I: [Pointing to a model of the methane molecule, CH_4]. What do the sticks represent?
M2: The atoms mix together.
I: [Try showing the 2-D representations of the same molecules]. What do the lines represent?
M2: The atoms join together.
I: Have you heard of chemical bonds?
M2: [Appeared unsure and confused]
I: Ok. Now, what do the balls represent?
M2: Atom.
I: Good. Why do you think the balls have different colours and/or sizes?
M2: They are not same atoms.
I: So, the different colours and sizes represent …
M2: Atoms of different elements.

I: [Show actual ball-and-stick models of common molecules such as water, ammonia and methane]. Have you seen such models?
M3: [No response]
I: What do the sticks represent?
M3: They are combined together.
I: What do the balls represent?
M3: [Silence] I think molecule.
I: Does the ball represent a molecule or the whole thing represents a molecule?
M3: [Silence]
I: If I show a ball, what does it represent?
M3: Element … [appearing unsure again]
I: Why do the balls have different colours and/or sizes?
M3: The, … the difference of the atoms. Colours show atoms have different colours.
I: What do you mean when you said `atoms have different colours?
M3: [Trying to say something but not successful]
I: Ok. Why we cannot use, for example, all white balls to construct the model?
M3: They are different atoms.
I: Do you want to explain further?
M3: No.

The High group

All the participants in this group knew ball-and-stick models of common molecules such as water, ammonia and methane very well. They knew what the sticks and the balls represent. They also knew why the balls have different colours and/or sizes and could explain convincingly. They have sound conceptual understanding of the concepts of atom, molecules, element, compound, and chemical bonds such as covalent bonds.

I: [Showing ball-and-stick models of common molecules such as water, ammonia and methane]. What do the sticks represent?
H1: Represent the bonds between atoms.
I: What do the balls represent?
H1: The balls represent atoms.
I: Good. Why do the balls have different colours and or sizes?
H1: The different colours represent different atoms. The different sizes also represent different atoms. For example, hydrogen atom is smaller compared to carbon atom or oxygen atom.

I: [Showing ball-and-stick models of common molecules]. What do the sticks represent?
H2: Bonds between atoms.
I: What do the balls represent?
H2: The atoms.
I: Good. Why do the balls have different colours and or sizes?
H2: To represent different atoms, so that it is easy to recognize them.

I: [Showing ball-and-stick models of common molecules]. What do the sticks represent?
H3: Covalent bonds.
I: What do the balls represent?
H3: Atoms.
I: Why do the balls have different colours and or sizes?
H3: To represent different types of atoms or element.
I: Do you mean atoms or elements?
H3: Element.

Question 4 – Cl_2 and $Cl_2(g)$

To create or generate representations of Cl_2 and $Cl_2(g)$, participants need to know:

(i) the type of particles that make up chlorine gas or chlorine gas exists as diatomic molecules (Cl_2),

(ii) the arrangement of particles in the gaseous state,

(iii) the meaning of the symbol (g), and

(iv) the difference between a one-particle and a many-particle system.

<u>The Low group</u>

All the three participants knew the symbols Cl_2 and $Cl_2(g)$ are different but could not tell or explain the difference, and could not use drawing to show either. They had no idea what a one-particle system and a many-particle system is. L2 also did not know what `Cl' represents. He had seen the symbol (g) but thought that (g) means `gram'. L3 knew the meaning of `Cl' but not `Cl_2'. He also thought that (g) means `gram'.

I: [Show two symbolic representations: Cl_2 and Cl_2 (g)]. Are the symbols Cl_2 and Cl_2 (g) different?
L1: Yes.
I: Can you use drawing(s) to show the difference?
L1: [Trying to draw something but nothing appeared on the paper].
I: You know they are different?
L1: Yes. But I don't know how they are different.
I: [Pointing to the symbol Cl_2 (g)]. What is the meaning of (g)?
L1: Gas
I: So what is the difference between the symbols Cl_2 and Cl_2 (g)?
L1: Don't know.

I: Do the symbols Cl_2 and Cl_2 (g) mean the same thing to you?
L2: No.
I: What is the difference between the two symbols?
L2: Don't know.
I: Maybe you can use drawing(s) to show the difference.
L2: [No response and nothing appeared on the paper provided]
I: What does `Cl' represent?
L2: Don't know.
I: How about (g)?
L2: `g' mean gram.
I: Have you seen the symbol (g)?
L2: I forgot already.

I: [Show two symbolic representations: Cl_2 and Cl_2 (g)]. What is the meaning of ` Cl_2'?
L3: [No response]
I: What is the meaning of `Cl'?
L3: Chlorine.
I: So, what is the meaning of `Cl_2'?
L3: 2 chlorine.
I: What about Cl_2 (g)?
L3: Also same.
I: What is the meaning of (g)?
L3: Gram.
I: Why gram? (g) in this case means `gas'. So are the symbols Cl_2 and Cl_2 (g) different?
L3: Yes.
I: Can you use drawing(s) to show the difference? L3: [Trying hard to draw something but nothing appeared on the paper].
I: You think they are different?
L3: Yes. But I don't know the difference.

The Medium group

Participants in this group still had some confusion between atom and molecule, as well as between atom and element, unsure of physical states of matter, and had no idea what is a one-particle and a many-particle system. They seemed to know the difference between the two symbolic representations but all of them did not know the difference. While M1 and M2 gave the wrong explanation, M3 could not tell the difference. He tried using drawing to show the difference but it was incorrect (see Figures 5.22). M1 was also confused between atom and molecule and had some confusion on chemical symbols (see Figures 5.20). M2 also had confusion with symbolic representation. He said Cl_2 was a liquid because it was not a gas. M3 knew $Cl_2(g)$ represented chlorine gas but showed O (an atom) instead of OO (a molecule). When questioned, he explained that Cl is an element. This provided evidence of his confusion between atom and element again.

I: [Show two symbolic representations: Cl_2 and Cl_2 (g)]. Do the symbols Cl_2 and Cl_2 (g) mean the same thing to you?
M1: First one is an atom. Second one is (g) represent atoms of a gas.
I: Can you use drawing(s) to show the difference?
M1: How about writing?
I: It will be easier to see the difference if you use drawing(s).
M1: [Drawing]. See Figure 5.20.

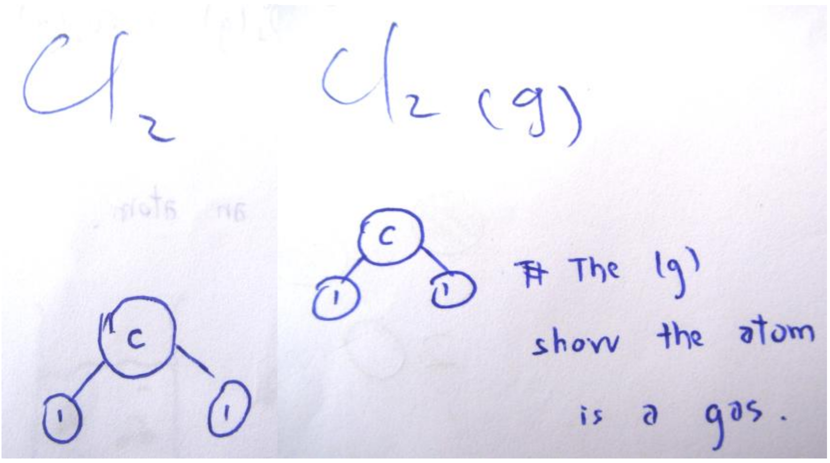


Figure 5.20: M1c

I: Do the symbols Cl_2 and Cl_2 (g) mean the same thing to you?
M2: Cl_2 represent chlorine gas.
I: What about Cl_2 (g)?
M2: Molecule gas
I: I don't understand what you mean. Can you draw to show the difference between Cl_2 and Cl_2 (g)?
M2: [Taking a long time to draw]. (See Figure 5.21)
I: Is there anything you want to label?
M2: [Label diagram]. (Showing the atom)
I: So to you Cl_2 and Cl_2(g) are the same?
M2: Cl_2 maybe is liquid because it is not a gas. Cl_2(g) is a gas.
I: But you said earlier that Cl_2 represent chlorine gas?
M2: [Appeared confused and unsure]

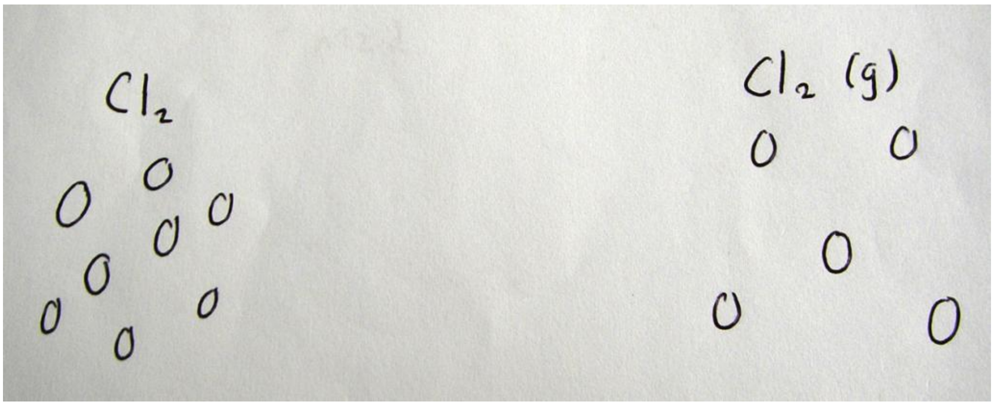


Figure 5.21: M2b

I: Do Cl_2 and Cl_2 (g) mean the same thing to you?
M3: No.
I: Can you use drawing(s) to show the difference?
M3: [Drawing]. See Figure 5.22.
I: [Looking at the drawing (Figure 5.22). Do you want to change anything on your drawing?
M3: No.

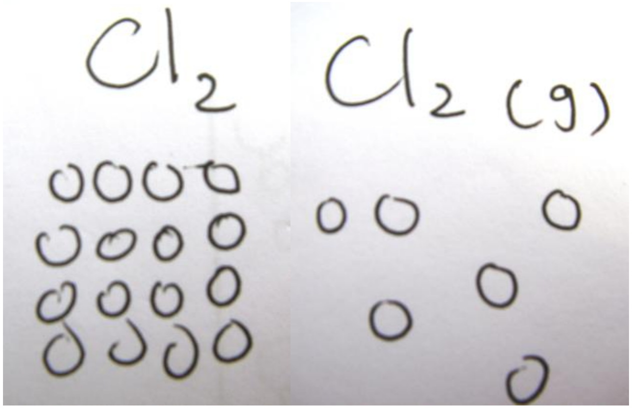


Figure 5.22: M3c

The High group

Participants in this group knew the two symbolic representations mean different things, familiar with the physical states of matter, seemed to know the difference between a one-particle and a many-particle system but not very sure, except H3. H1 and H2 could distinguish between a one-particle and a many-particle system in words but not in drawing (Figures 5.23 and 5.24). Only H3 could explain the difference between a one-particle and a many-particle system, and provided a clear illustration (Figure 5.24).

I: Do the symbols Cl_2 and $Cl_2\,(g)$ mean the same thing to you?
H1: No, they mean different things.
I: Can you use drawing(s) to show the difference?
H1: [Drawing]. See Figure 5.23.

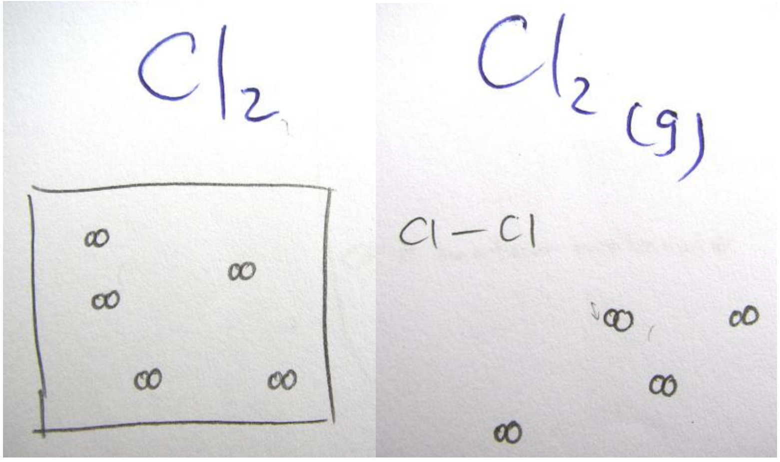


Figure 5.23: H1b

I: [Looking at the drawing (Figure 5.23). Then pointing at the diagram and ask] `what is this'?
H1: $Cl_2\,(g)$ is chlorine gas. Cl_2 is chlorine molecules but not necessarily in gaseous state.
I: So, what is the difference between Cl_2 and $Cl_2\,(g)$? Can you explain your drawing?
H1: [Pointing at 2 small circles in the figure and explaining]. This is Cl_2 molecule.
I: If Cl_2, how many molecules of Cl_2 are you going to draw?
H1: [Still drawing more than one molecule of Cl_2]. There are a lot of molecules. $Cl_2\,(g)$ also show it is a gas.
I: Do you agree if I say ` Cl_2' refers to a molecule of chlorine?
H1: Yes.
I: Would you like to change anything on the diagram?
H1: No.

I: Do the symbols Cl_2 and $Cl_2\,(g)$ mean the same thing to you?
H2: [Looking at the representations and thinking]. No, they are different.
I: How would you use drawing(s) to show they are different?
H2: [Drawing for a long time]. See Figure 5.24.
I: [Pointing at the drawing and asking]. Can you explain why are the two representations different?
H2: $Cl_2(g)$ stated that chlorine molecules are in the gaseous state, while Cl_2 doesn't state that but only in molecular form.

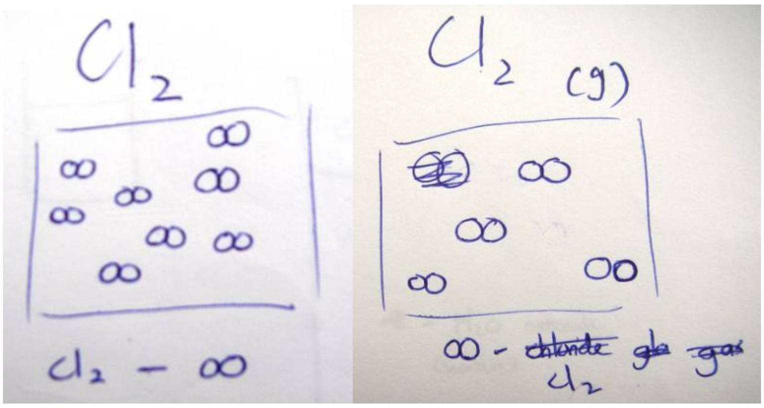


Figure 5.24: H2c

I: Do the symbols Cl_2 and Cl_2 (g) mean the same thing to you?
H3: 1st one represents the particle. 2nd one represents the state of the particle.
I: How would you use drawing(s) to show they are different?
H3: [Drawing]. See Figure 5.25.
I: [Pointing at the drawing]. Can you explain your drawing?
H3: [Looking at the diagram and thinking but did not explain].
I: [Pointing to Figure 5.25]. Normally you use this to refer to one chlorine molecule?
H3: Yes.

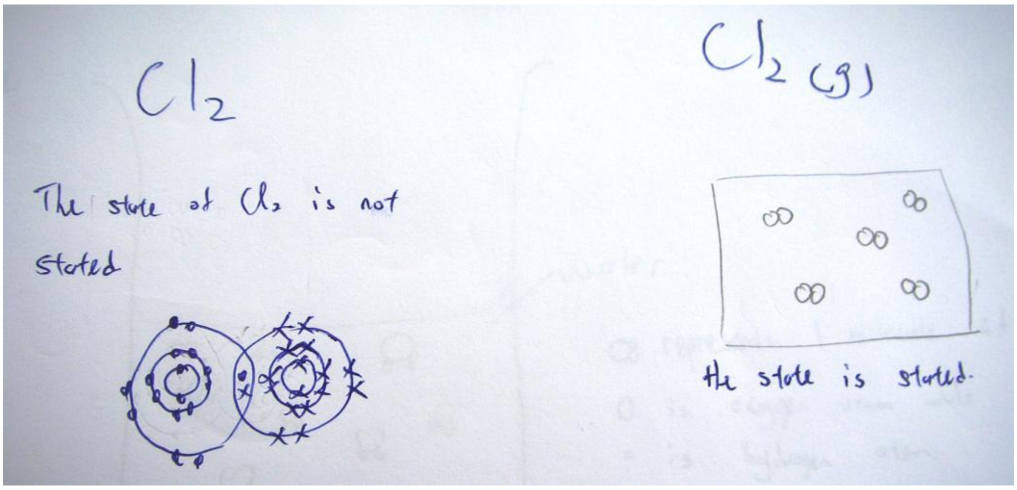


Figure 5.25: H3c

5.5.1.4 Submicroscopic representations

Question 1 – Online Quiz

To answer the online quiz on submicroscopic representations, participants need to have sound conceptual understanding of the basic chemical concepts of: (i) pure substances and mixtures, (ii) elements and compounds, and (iii) atoms and molecules. They must also be able to distinguish between the pair of concepts (such as atoms and molecules), and also among the concepts (such as atoms and elements, molecules and compounds) as confusion may arise between the concept of atom (microscopic) and element (macroscopic), and also the concept of molecules (microscopic) and compound (macroscopic), as learners are either unsure of the two worlds of chemistry or cannot link between these two levels of representation of matter. Confusion may also arise as learners tend to associate the concepts of `atom' with `element' and `molecule' with `compound'.

The Low group

The participants took about 5 minutes to complete the quiz. The scores were respectively 7/7 or 100% (L1), 3/7 or 42% (L2), and 2/7 or 28% (L3). L2 and L3 could not explain why they chose a certain option. However, L1 seemed to do the quiz with understanding and could explain why he chose the correct option. As a check on the reliability of his score, L1 was asked to do the same quiz again a week later. The score was 6/7 or 71% but he quickly corrected his mistake and again got all correct answers.

I: Work through the online quiz available at www.darvill.clara.net/hotpots/emc.htm (*Appendix 25a*).
L1: Working on the quiz.
I: [Surprised to see L1's perfect score for the online quiz]. Your score is 100%.
L1: [Participant appeared happy but calm to see the score of 100%]
I: [Pointing to each of the option correctly selected by the respondent and asking him why he chose each option. L1 can explain why he chose the correct option!]

Note: L1 was placed in the Low group based on his TRC score of 4 points. However, his score for the CTSR was 10. (See Table 4.10: Profile of the interview participant).

The Medium group

The participants in this group took longer time (between 5 to 8 minutes) to complete the quiz. Their scores were the same. That is 4/7 or 57%. All their four correct items (items 4 to 7) were the same. However, they chose different options for the three wrong items, that is: items 1 to 3 (see Table 5.21). Although they seemed to know about pure substances and mixture, elements and compounds, their mistakes showed there were still confusion between basic chemical concepts, in particular atoms and molecules. A copy of the online quiz is provided in *Appendix 25a* and also available online at www.darvill.clara.net/hotpots/emc.htm

Table 5.21
Participants' varying options for their wrong responses in the online quiz

Participant	Options		
	Item 1	Item 2	Item 3
M1	C	A, C & D	A & D
M2	H	A, C & D	G
M3	A & D	C	A, C & D

<u>The High group</u>

All the three participants took less than 5 minutes to complete the online quiz, with scores of 7/7 or 100%. They had clear conceptual understanding of basic chemical concepts of pure substances and mixtures, element and compounds, atoms and molecules and had no problem with submicroscopic representations of these basic chemical concepts. Hence they were able to relate these concepts with the appropriate submicroscopic representations easily.

Question 2 – Worksheet (1) (see Appendix 25)

Although Worksheet (1) and the Online Quiz appear similar, the inclusion of Worksheet (1) serves as triangulation for the findings of the Online Quiz. In addition, participants were further assessed on their ability to explain the criteria of classification.

Table 5.22
Scores of the participants for Worksheet (1)

Participants / Part/Section	(1) Pure substances & mixtures	(2) Elements & compounds	Total score
L1	2/8	0/5	2
L2	5/8	5/5	10
L3	4/8	0/5	4
M1	3/8	2/5	5
M2	2/8	1/5	3
M3	4/8	3/5	7
H1	8/8	5/5	13
H2	6/8	5/5	11
H3	8/8	5/5	13

Note: H=High; M=Medium; L=Low

<u>The Low group</u>

The three participants either could not explain how to classify pure substances and mixtures, elements and compounds, or gave the wrong explanation, or use the wrong criteria to classify them. See Figures 5.26 to 5.28.

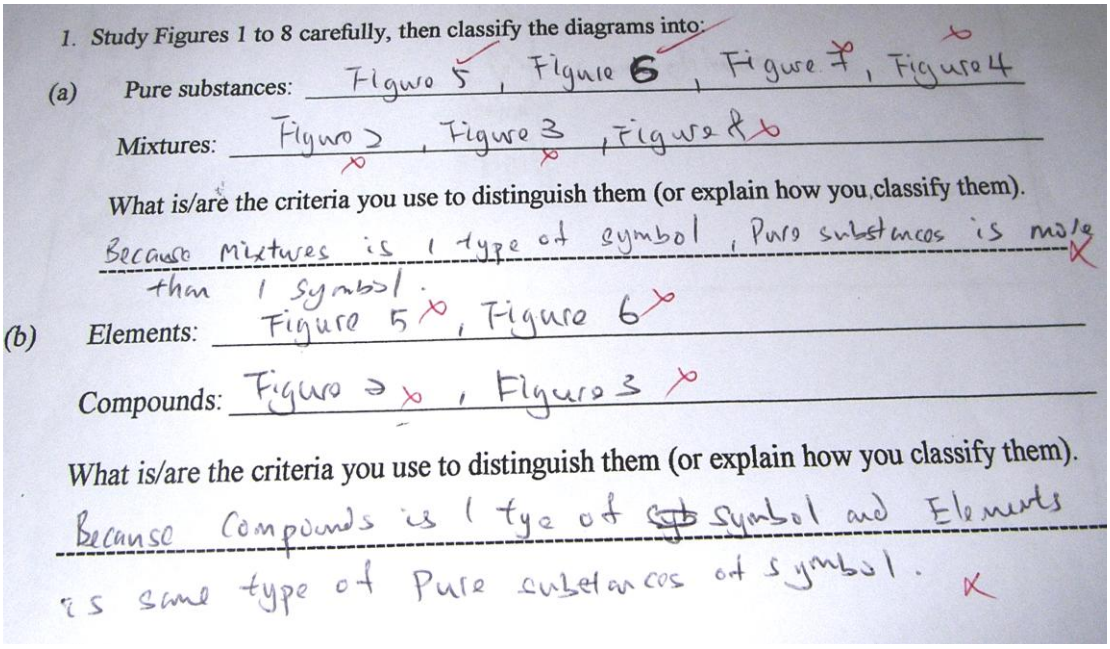
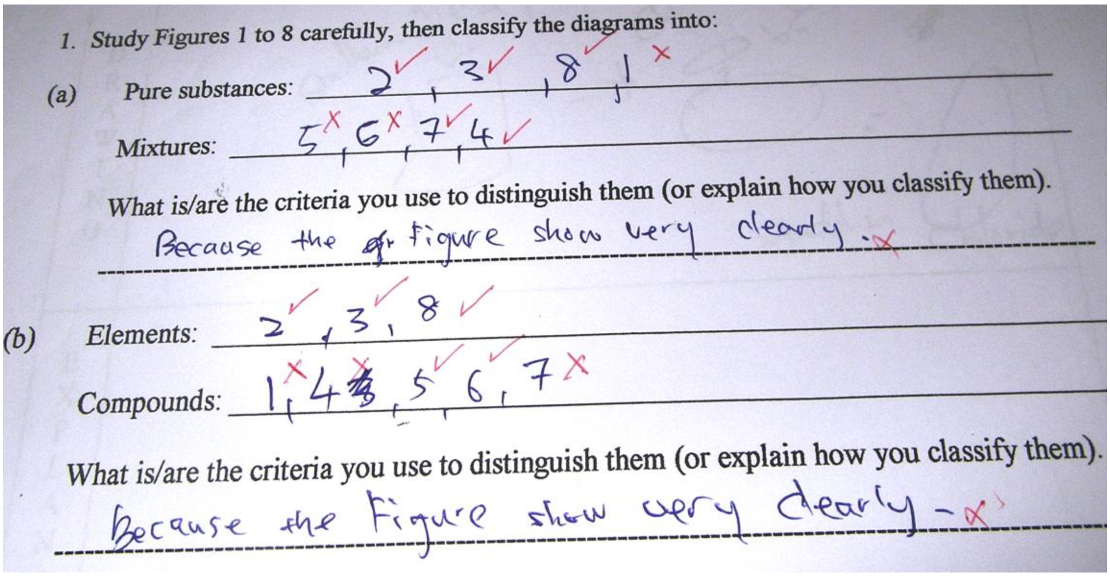

1. Study Figures 1 to 8 carefully, then classify the diagrams into:
(a) Pure substances: Figure 5, Figure 6, Figure 7, Figure 4
Mixtures: Figure 2, Figure 3, Figure 8
What is/are the criteria you use to distinguish them (or explain how you classify them).
Because mixtures is 1 type of symbol, Pure substances is more than 1 symbol.
(b) Elements: Figure 5, Figure 6
Compounds: Figure 2, Figure 3
What is/are the criteria you use to distinguish them (or explain how you classify them).
Because compounds is 1 tye of symbol and Elements is same type of Pure substances of symbol.

Figure 5.26: L1b


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: 2, 3, 8, 1

Mixtures: 5, 6, 7, 4

What is/are the criteria you use to distinguish them (or explain how you classify them).

Because the figure show very clearly.

(b) Elements: 2, 3, 8

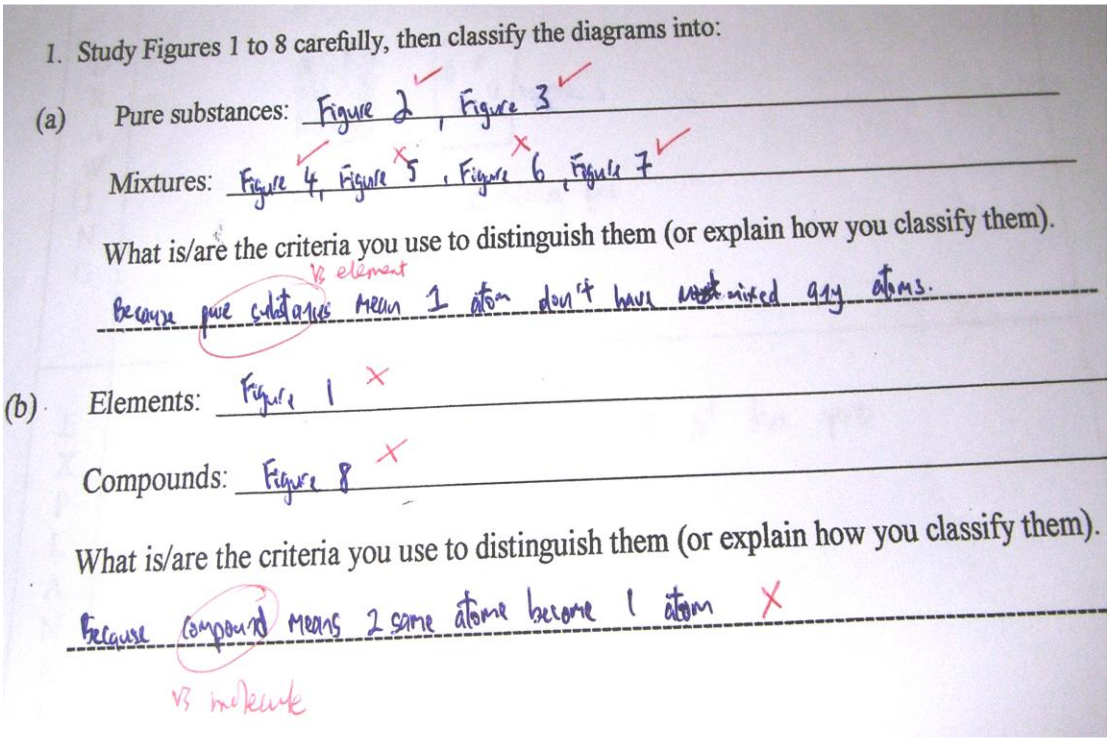
Compounds: 1, 4, 5, 6, 7

What is/are the criteria you use to distinguish them (or explain how you classify them).

Because the Figure show very clearly -

Figure 5.27: L2d

L3's confusion between the concepts pure substances with elements, and compounds with molecules, led him to choose the wrong submicroscopic representations (Figure 5.28).


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: Figure 2, Figure 3

Mixtures: Figure 4, Figure 5, Figure 6, Figure 7

What is/are the criteria you use to distinguish them (or explain how you classify them).

Because pure substances mean 1 atom don't have mixed any atoms.

(b) Elements: Figure 1

Compounds: Figure 8

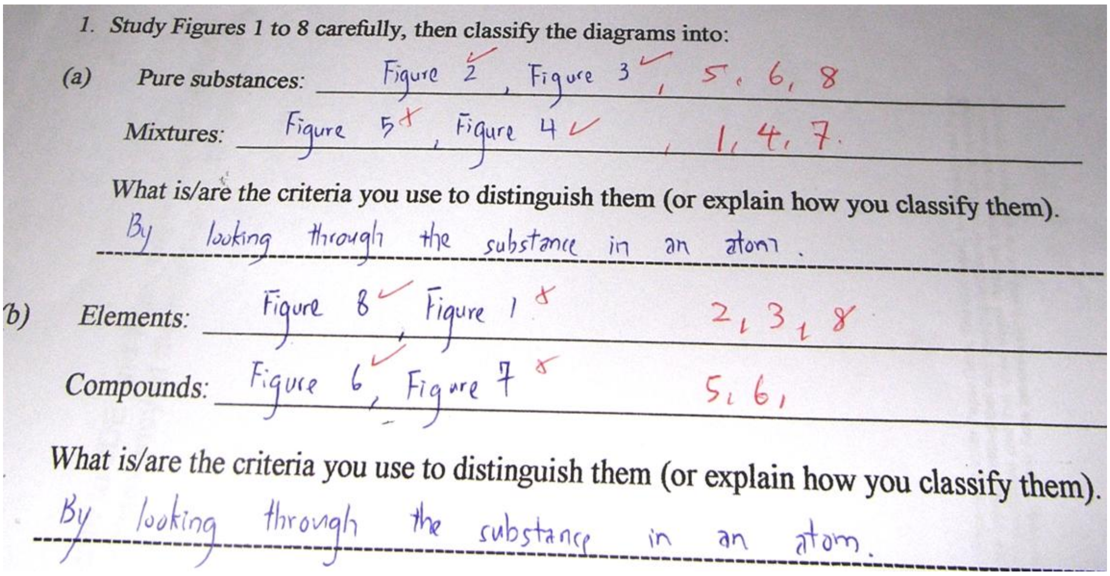
What is/are the criteria you use to distinguish them (or explain how you classify them).

Because compound means 2 same atoms become 1 atom

Figure 5.28: L3d

The Medium group

Participants in this group managed to get some correct answers but could not explain the criteria of classification (Figures 5.29 and 5.30).


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: Figure 2, Figure 3, 5, 6, 8

Mixtures: Figure 5, Figure 4, 1, 4, 7.

What is/are the criteria you use to distinguish them (or explain how you classify them).

By looking through the substance in an atom.

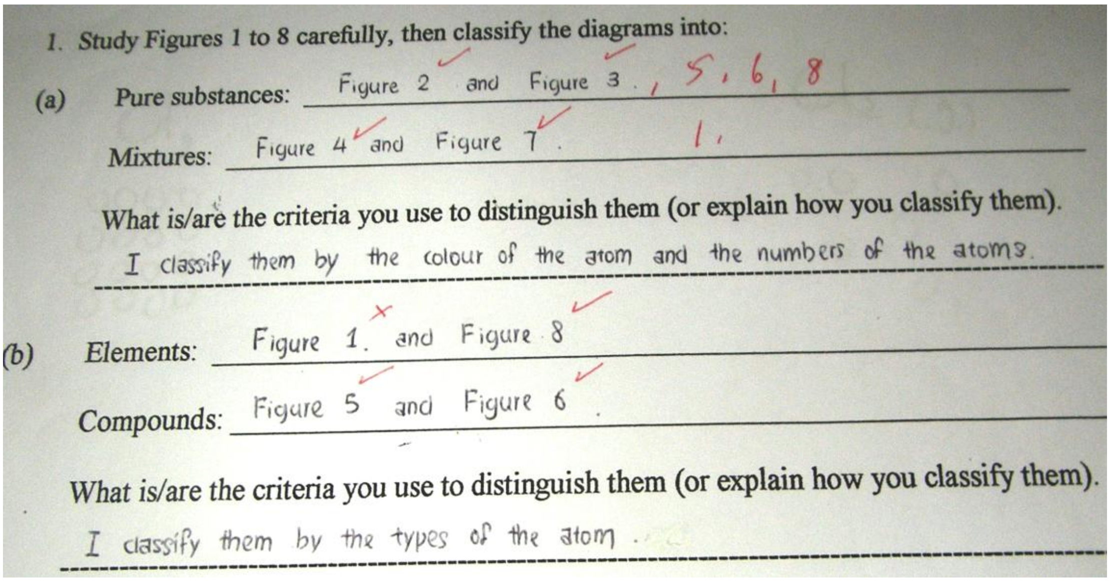
(b) Elements: Figure 8, Figure 1 2, 3, 8

Compounds: Figure 6, Figure 7 5, 6,

What is/are the criteria you use to distinguish them (or explain how you classify them).

By looking through the substance in an atom.

Figure 5.29: M1d


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: Figure 2 and Figure 3, 5, 6, 8

Mixtures: Figure 4 and Figure 7. 1,

What is/are the criteria you use to distinguish them (or explain how you classify them).

I classify them by the colour of the atom and the numbers of the atoms.

(b) Elements: Figure 1. and Figure 8

Compounds: Figure 5 and Figure 6.

What is/are the criteria you use to distinguish them (or explain how you classify them).

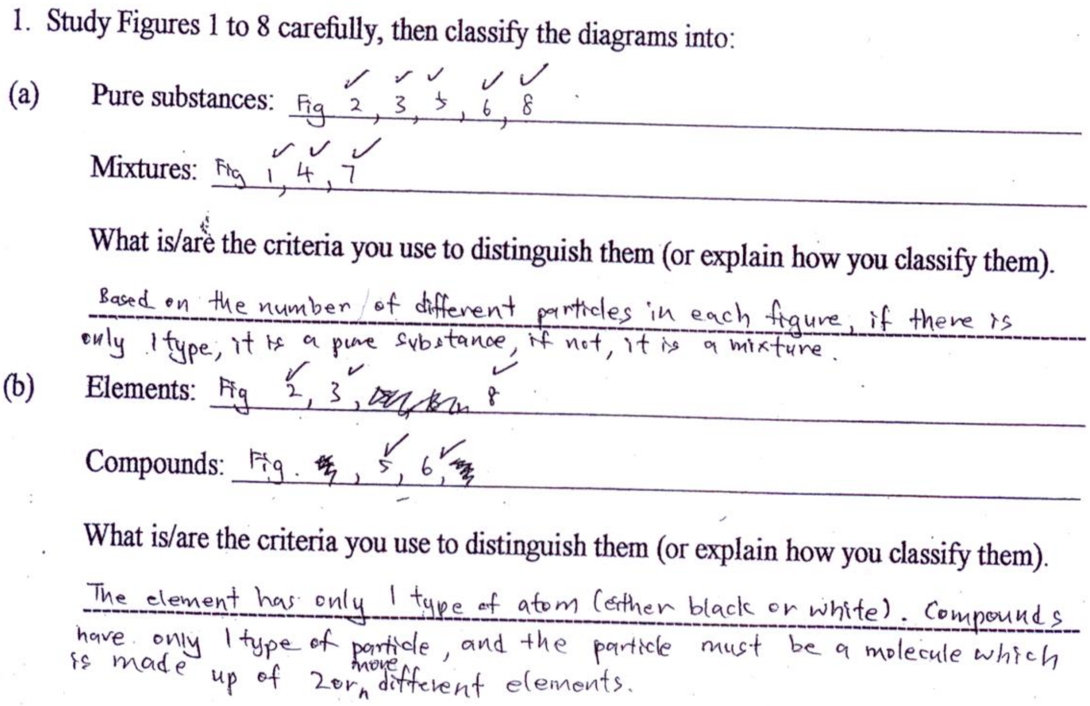
I classify them by the types of the atom.

Figure 5.30: M3d

The High group

Of the three participants, only H1 and H3 chose all the correct options and were able to explain how to classify pure substances and mixtures, elements and compounds (Figures 5.31 and 5.33). They had sound conceptual understanding of the terms pure substances and mixtures, elements and compounds, knew the particles of matter such as atoms and molecules well, and were very familiar with submicroscopic representations of the above basic chemical concepts. Hence, they could relate these concepts with the appropriate representations and could also explain their choice clearly and precisely.

H2, however, had confusion between pure substance and element. He thought that pure substance can only contain atoms of one kind, without realising that a compound also can be a pure substance (Figure 5.32). A closer look at the answer of H1 shows he also had confusion over the types of particles in a compound. Although he was correct to explain that a compound is made up of two or more elements, the type of particles is not restricted to molecules only. It could be also ions.


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: Fig 2, 3, 5, 6, 8

Mixtures: Fig 1, 4, 7

What is/are the criteria you use to distinguish them (or explain how you classify them).

Based on the number of different particles in each figure, if there is only 1 type, it is a pure substance, if not, it is a mixture.

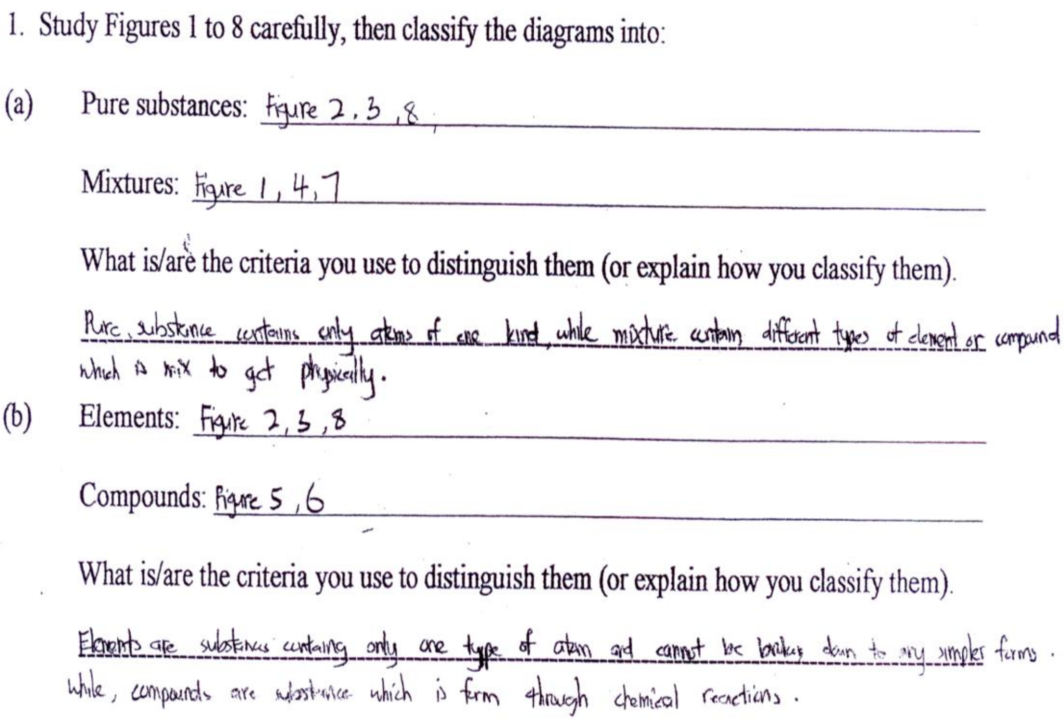
(b) Elements: Fig 2, 3, 8

Compounds: Fig. 5, 6

What is/are the criteria you use to distinguish them (or explain how you classify them).

The element has only 1 type of atom (either black or white). Compounds have only 1 type of particle, and the particle must be a molecule which is made up of 2 or more different elements.

Figure 5.31: H1c


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: Figure 2, 3, 8,

Mixtures: Figure 1, 4, 7

What is/are the criteria you use to distinguish them (or explain how you classify them).

Pure, substance contains only atoms of one kind, while mixture contain different types of element or compound which is mix to get physically.

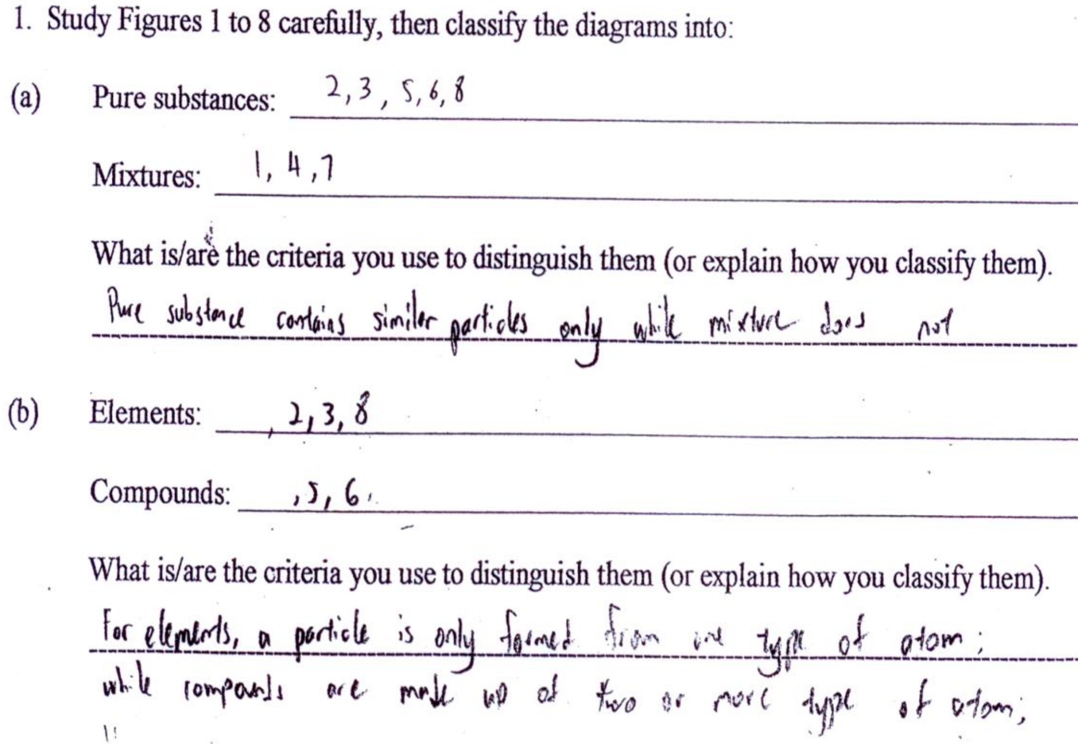
(b) Elements: Figure 2, 3, 8

Compounds: Figure 5, 6

What is/are the criteria you use to distinguish them (or explain how you classify them).

Elements are substances containing only one type of atom and cannot be broken down to any simpler forms. while, compounds are substance which is form through chemical reactions.

Figure 5.32: H2d


1. Study Figures 1 to 8 carefully, then classify the diagrams into:

(a) Pure substances: 2, 3, 5, 6, 8

Mixtures: 1, 4, 7

What is/are the criteria you use to distinguish them (or explain how you classify them).

Pure substance contains similar particles only while mixture does not

(b) Elements: 2, 3, 8

Compounds: 5, 6

What is/are the criteria you use to distinguish them (or explain how you classify them).

For elements, a particle is only formed from one type of atom; while compounds are made up of two or more type of atom;

Figure 5.33: H3d

5.5.2 Students' representational competence

In this section, further insights and understanding into the participants' representational competence were examined through SSI (2), using Interview Protocol (2) as a guideline. SSI (2) comprises three parts. Part 1 re-examines selected questions based on items in the TRC, Part 2 focuses on student-generated generations while Part 3 looks at multiple levels of representations.

5.5.2.1 Questions based on items in the TRC

Part A – Items 19 & 22 (see Appendix 15a)

Items 19 and 22 specifically assess participants' ability to translate across levels of representations, that is: from submicroscopic level (such as a particulate or molecular drawing) to symbolic level (such as a chemical equation). Sound conceptual understanding of a chemical equation is required to demonstrate this ability. Although both items assessed the same ability, it was not a repetition but rather, verification. Participant who scored one item correctly and the other incorrectly probably chose the correct option through guessing. Of the nine participants, eight of them either scored both the items correctly or both were incorrect. Such findings were consistent and added reliability to the test scores of the TRC.

<u>The Low group</u>

L1 and L2 chose option `C' as answer for item 19 and were very surprised to know `B' was the correct answer. L1 also questioned why `A' was incorrect. L3 chose the correct option for item 22 but could not explain why. Excerpts from the interview transcripts provide further insights:

I: [Showing a copy of the Test on Representational Competence, TRC (see *Appendix 15a*) to the participant]. What do you think is the correct answer for Question 19?
L1: [Reading the question and looking at the diagram for a long time]. The answer is `C'.
I: Why do you choose `C' as the answer?
L1: Because I look at the diagram. There are 6 atoms of X and 9 atoms of Y. Then the chemical equation is like this (pointing at option `C': $6X + 9Y \rightarrow 4XY_2 + 2X + Y$). So I choose `C'. It is the same as the diagram.
I: But `C' is not the correct answer.
L1: So what is the correct answer? [L1 appeared very interested to know the correct answer]
I: `B'
L1: [Appeared surprised!] Why?
I: In chemical equation, you only include the reactants and the products, the excess reagents are not included.
L1: [Silence but apparently thinking]. Why is `A' not the answer?
I: Answer `A' is not the simplest. [Showing the participant how to get the correct answer `B'.

I: Let's look at Questions 19 of Part A. What do you think is the correct answer?
L2: [Reading the question and looking at the diagram for a long time]. The answer is `C'.
I: Why do you choose `C' as the answer?
L2: Because has 6 atoms of X and 9 atoms of Y.
I: What is $4XY_2$ in the equation? [Pointing at option `C']
L2: [No response]
I: Can you identify $4XY_2$ in the diagram?
L2: [Looking at the diagram but could not identify anything]
I: The correct answer is `B'.
L2: ah? [Looking so surprised]

I: What do you think is the correct answer for Question 19?
L3: [Reading the question and looking at the diagram for a long time]. `C'.
I: Why do you choose `C' as the answer?
L3: Atoms X has 6, Y got 9, then become $4XY_2 + 2X + Y$
I: So you are comparing the diagram with the equation?
L3: Ya.
I: A lot of people (about 65%) chose `C' but it is not the correct answer. In chemical equation, you only include the reactants and the products.
L3: [Listening]
I: Can you tell me the difference between options `A' and `B'?
L3: Just divide.
I: Is Qu. 22 similar to Qu. 19?
L3: Ya.
I; What do you think is the answer for Qu. 22?
L3: `D'.
I: You also chose `D' in your test TRC! Can you explain why you chose `D'?
L3: [Apparently thinking]. Don't know how to explain.
I: But you know `D' is the correct answer?
L3: Yes, similar to Qu. 19.

<u>The Medium group</u>

All the three participants in this group chose `C' as their answer. They all gave reason for their choice and were equally surprised the correct answer was `B'. See excerpts from the interview transcripts below.

I: Now, let’s look at Questions 19 and Question 22 of Part A.
M1: [Participants saw that his responses to these two questions were wrong]
I: Why did you choose `A’ as your answer for question 19?
M1: [Looking at the question and thinking]… Then said: I think the correct answer is `C’, and changed the answer from `A’ to `C’.
I: Why do you choose `C’?
M1: I look at the number of atoms in the box. Number of atoms of X is 6. Number of atoms of Y is 9. Then the chemical equation is like this (pointing at option `C’).  So I choose `C’.

I: [Read out Question 19 aloud]
M2: [Taking a long time to look at the diagram in Qu.19 and the options A, B, C and D]. I think I choose `C’
I: Why did you choose `C’?
M2: I think… I compare the number and types of atoms before and after the reaction with the chemical equation. They are the same.
I: But the correct answer is `B’
M2: Why? [M2 appeared very surprised, can’t believe it!]

I: What do you think is the answer for question 19?
M3: [Reading the question and thinking]… Then said: Answer is `C’.
I: You also chose `C’ in your test TRC.  Why do you choose `C’ as the answer?
M3: Look at the drawing.
I: You look at the drawing, then compare it with the equation?
M3: Yes.

The High group

All the three participants chose the correct option `B’ in the test as well as during the interview.  They could explain why they chose `B’ but didn’t choose `C’ and `A’. They also chose the correct option `D’ for item 22. They did not encounter any difficulty translating submicroscopic representation to symbolic representation such as a chemical equation. Excerpts from the interview transcripts show they had sound understanding of the concept of a chemical equation:

I: [Showing a copy of the TRC to the participant]. What answer would you give for item no. 19?
H1: [Working on the question and responding fast]. The answer is `B’.
I: You also chose `B’ in your test.  The most popular answer is `C’. Why didn’t you choose `C’?
H1: [Pointing to the diagram in Qu. 19]. These are the excess reagents. In chemical equation, only include the reactant and the products.
I: Why didn’t you choose `A’?
H1: Because `B’ is the simplest.
I: Good. Shall we look at item no. 22?
H1: [Working on item no. 22]. The correct answer is `D’.

I: Look at Questions 19 and 22 of Part A. What do you think is the answer for Qu. 19?
H2: [Working on Qu. 19]. The answer is `B’.

I: You also chose `B' in your test. Why didn't you choose `C'?
H2: [Pointing to the diagram in Qu. 19]. In chemical equation, only the reactants and the products are included. The equation in `C' includes unreacted reactants.
I: Why didn't you choose `A'?
H2: Because `A' is not the simplest.
I: Shall we look at Qu. 22?
H2: [Working on Qu.22]. The correct answer is `D'.
I: Ok, good.

I: What would be your answer for Qu. 19?
H3: [Working on Qu. 19]. The answer is `B'.
I: You also chose `B' in your test. Why didn't you choose `C'?
H3: [Pointing to the diagram in Qu. 19]. For the equation $X + 2Y \rightarrow XY_2$, the reaction is complete.
I: Why didn't you choose `A'?
H3: Because the question asks for the simplest equation.
I: Lets' look at Qu. 22.
H3: [Working on Qu.22]. The answer is `D'.
I: Ok, good. Both your answers are correct.

Part B – Items 3(a) and 3(c)

To represent the concepts correctly, participants need to know and understand the concepts of `atom' (a microscopic term), and `element' (a macroscopic term), as well as the relationship between the two concepts. They also need to know the types of particles in an element could be either atoms or molecules.

The Low group

The participants could not represent the chemical concepts correctly because they could not understand the concepts. L1 knew an atom and an element were different, could draw an atom but could not use drawing to represent an element (Figure 5.34). L2 did not know the difference between an atom and an element and could not draw anything in the test (TRC). When asked to draw to show an atom and an element during the interview, both drawings looked similar (see Figure 5.35). L3 also could not tell the difference between an atom and an element, as well as an atom and a molecule. In the test (TRC), he drew an atom but looks like a molecule, and an element looking like an atom (Figure 5.36).

I: Let's look at Question 3(c) of Part B. Does `an atom' and `an element' mean the same thing to you?
L1: No, they are different.
I: Why are you drawing a circle for part (c)? See figure 5.34.
L1: I didn't know how to draw an element, so I drew a circle.
I: Can you tell me the relationship between an atom and an element?
L1: An element maybe is made up of atoms.

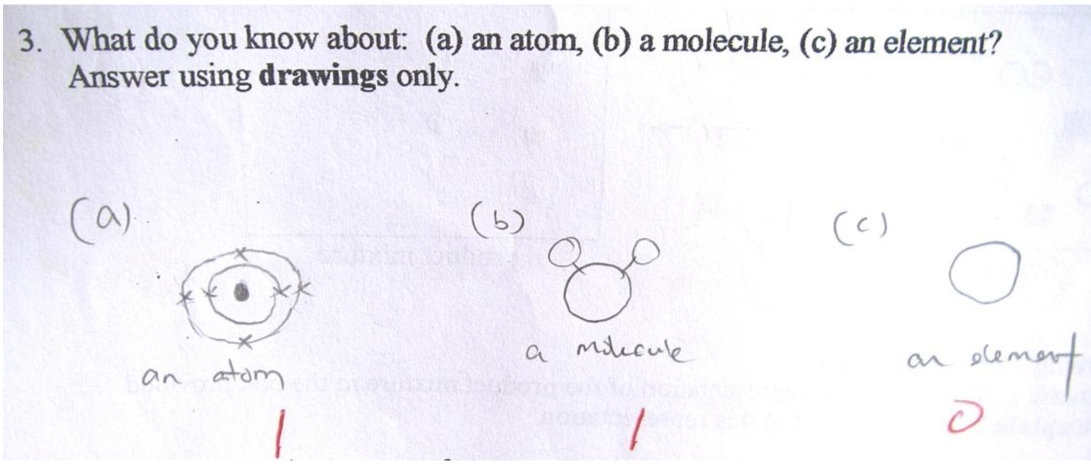
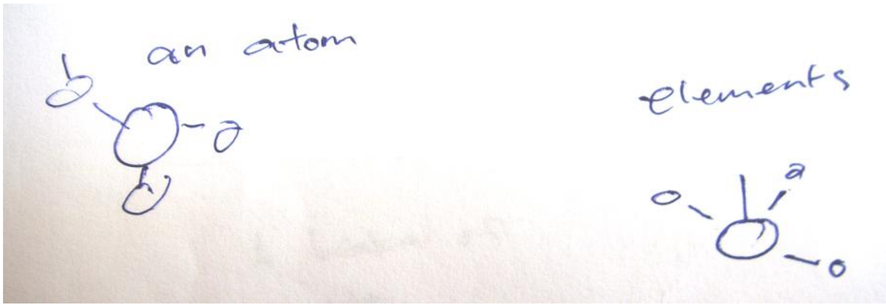


Figure 5.34: L1c

I: Now let's look at Question 3(c). Can you draw to show an atom and an element?
L2: [Drawing and labelling but both look similar]. See Figures 5.35.
I: Why are you drawing the same thing? So what is the difference between an atom and an element?
L2: Don't know.



Figures 5.35: L2e

I: Look at Question 3(c). Can you tell me the difference between an atom and an element?
L3: [No response]
I: How about the difference between an atom and a molecule?
L3: [Looking at his own drawing in the TRC] See Figure 5.36.
I: [Pointing to the drawing in Qu. 3 of Part B]. Why is the atom looking like a molecule and the element looking like an atom?
L3: Don't know.

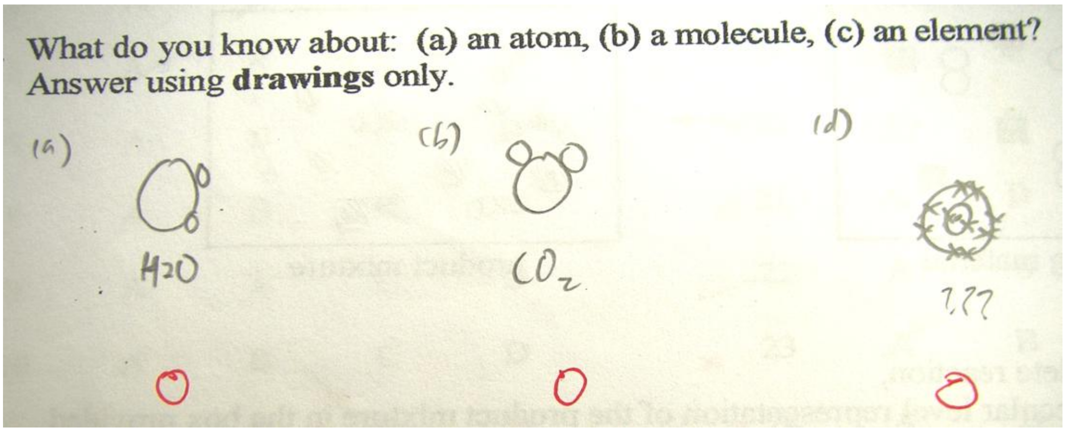


Figure 5.36: L3e

The Medium group

Participants seemed to be confused between certain basic chemical concepts. For example, they tend to associate atoms with elements. However, they could only represent an atom but not an element. For item 3(c), M1 drew a lot of similar circles and labelled `an oxygen element' (Figure 5.37). He explained that the drawing represented atoms of an element. However, the diagram was not acceptable as it was labelled as oxygen atoms, as oxygen exist as diatomic molecules. M2 drew many atoms and said an element has many atoms (Figure 5.38). He seemed to know the difference between an atom and an element. M3 thought that the symbol `Al' represented an element (Figure 5.39). He had no idea of the submicroscopic representation of an element.

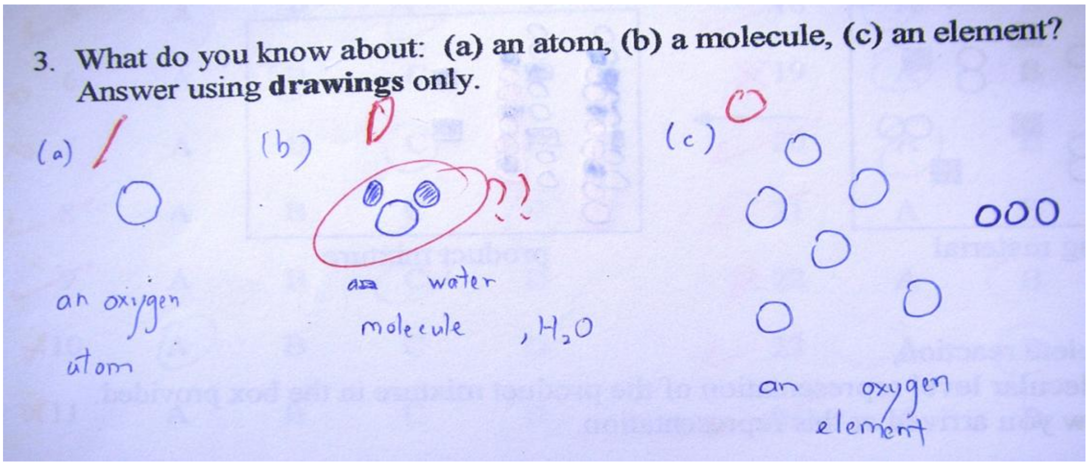


Figure 5.37: M1e

I: Now let's look at Question 3(c) of Part B. Why did you draw a lot of atoms (Figure 5.37)? What does the drawing represent?
M1: An element, atoms of an element.
I: Does oxygen exist as atoms? Your diagram is acceptable if you did not label as oxygen.

I: Let's look at Question 3(c). Why did you draw so many atoms (Figure 5.38)?
M2: [Silence]
I: What is the difference between an atom and an element?
M2: An element has many atoms.
I: Can you see an atom?
M2: No.
I: Can you see an element?
M2: Yes.
I: Ok. You seem to know the difference.

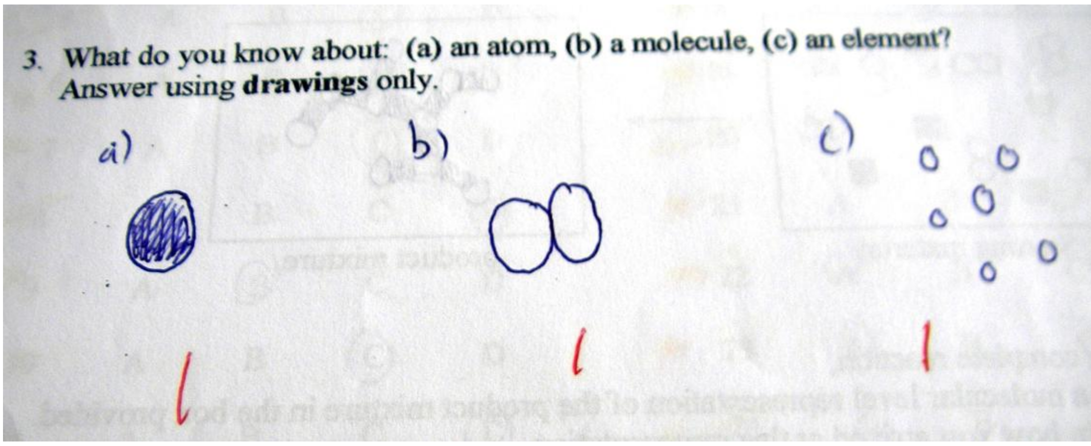


Figure 5.38: M2c

I: Now let's look at Question 3(c) of Part B.
M3: [Looking at his own answer in the TRC]   See Figure 5.39.
I: Why did you write `Al'?  What does `Al' represent?
M3: [Not responding]

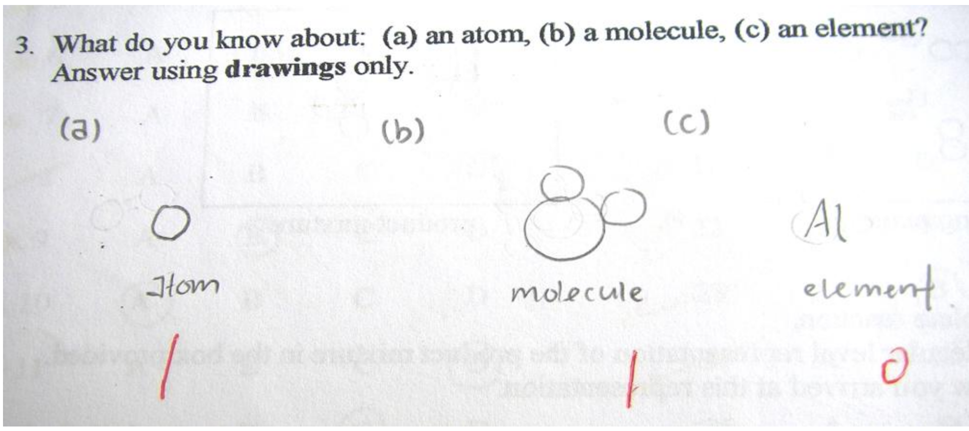


Figure 5.39: M3e

The High group

All the participants knew the difference between an atom and an element and could distinguish between them. They could represent an atom and an element correctly (Figures 5.40, 5.41, and 5.42), but still tended to associate elements with atoms only. Among the three participants, H1 was unique in that he could represent beyond the atomic level, showing the structure of an atom and the sub-atomic particles. However, none of them identified molecules as the type of particles in an element and only did so when prompted or probed further. See excerpt from interview transcript of H1 below:

I: Let's look at Question 3(a) and (c) of Part B.
H1: [participant looking at his answer script. His answers to both parts were correct (Figure 5.40).
I: What do you think is the difference between an atom and an element?
H1: An element has only one kind of atom. An atom is a single particle.
I: Can you explain how element and atom are related?
H1: An element is made up of one type of atom.
I: What is/are the type of particles found in an element?
H1: Atoms.
I: Only atoms?
H1: Atoms and molecules.

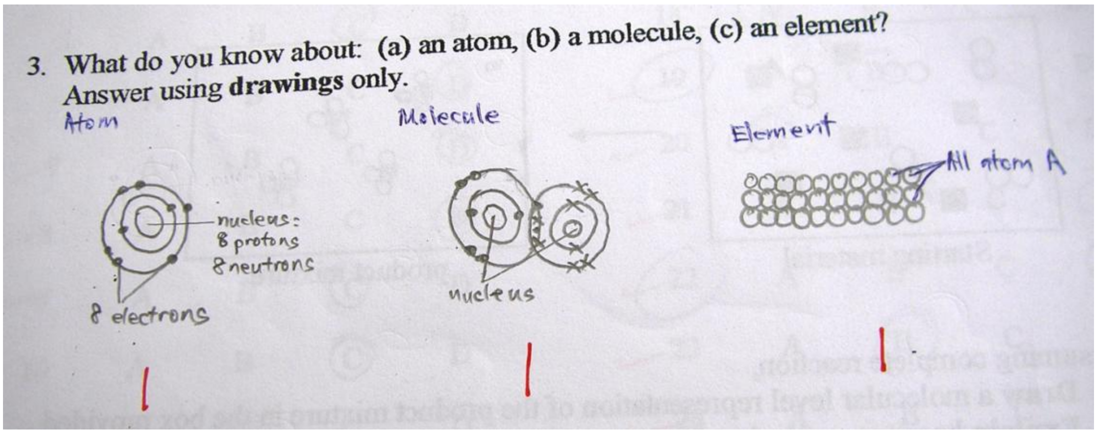


Figure 5.40: H1d

I: Now let's look at Question 3(a) and (c) of Part B.
H2: [participant's answers to both parts were also correct]. See Figure 5.41.
I: What is the difference between an atom and an element?
H2: Element consists of many atoms while atom is only a single particle.
I: Can you see an element?
H2: Yes.
I: Can you see an atom?
H2: No.

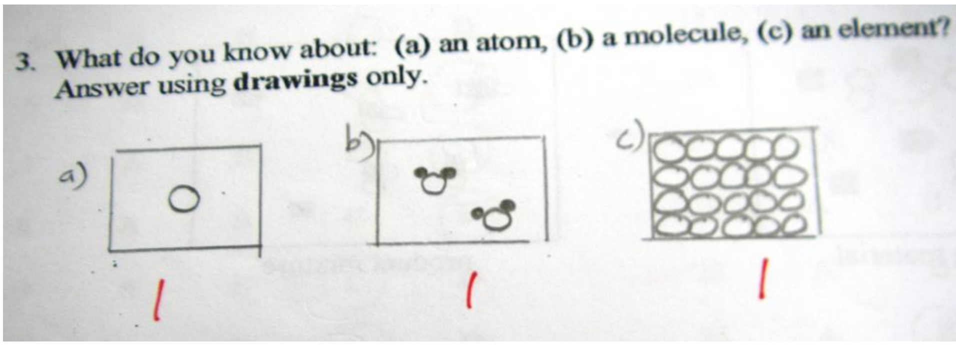


Figure 5.41: H2e

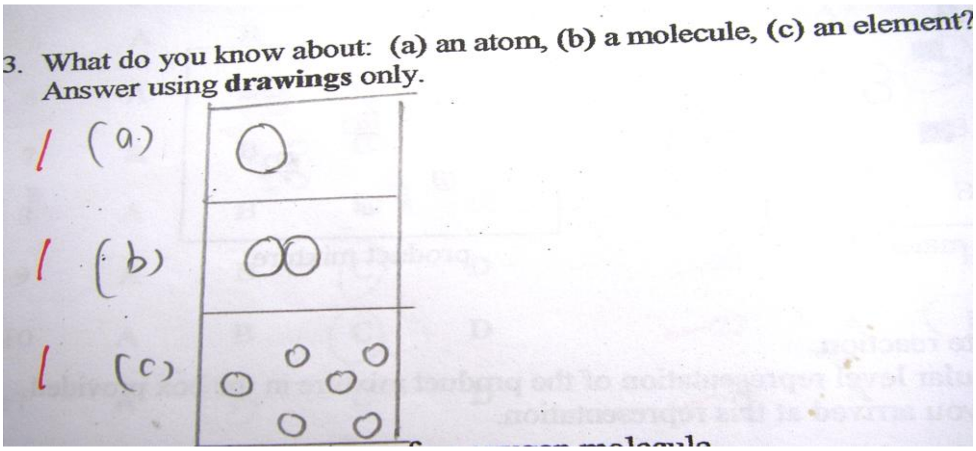


Figure 5.42: H3e

5.5.2.2 Student generated representations

In part 2, different substances were given and the participants were asked to use drawing(s) to represent the substances.

Question 1 – A beaker of water

To generate the representation correctly, participants need to know that water is a pure substance (compound), a liquid at room condition, that water is made up of water molecules, how a molecule of water looks like, and hydrogen bonding in water. This problem prompts the participants to use their understanding of the particulate nature of matter to transform their representation from a straight forward depiction of a beaker of water to a molecular depiction of water.

The Low group

There were only two drawings which show a microscopic view of water but only one drawing represented the water molecules correctly. However, the arrangement of particles does not depict that of a liquid. The drawing of L1 shows some black dots (Figure 5.43). L1 said the black dot is oxygen because there is oxygen in water. No water molecules were shown. L2's drawing shows two particles which according to the participant are atoms of water. There are some wavy lines which he said are virus because the water is dirty (Figure 5.44). It could be inferred that the participant had no knowledge of atom, molecules, and/or confusion between element, compounds, and other basic chemical concepts. L3's drawing shows many molecules of water. Correct chemical representation of water molecules was used but arrangement of the molecules does not depict that of a liquid as there are too closely packed (see Figure 5.45).

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
L1: [No response]
I: Can you draw to show how a beaker of water might appear when viewed through `a very powerful microscope'?
L1: [Long pause, and finally drawing something on the paper]. See Figure 5.43.
I: [Pointing to the black dots in Figure 5.43]. Can you tell me what do those black dots on your diagram represent?
L1: [No response]
I: Do you want to label anything?
L1: How to label?

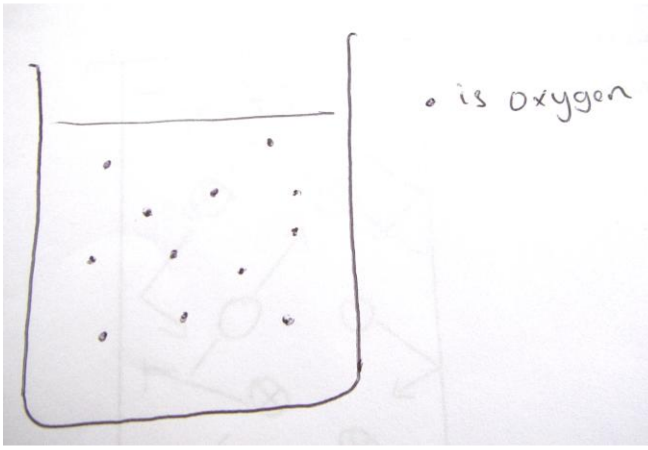


Figure 5.43: L1d

I: Just tell me what the black dots represent.
L1: [Writing down something beside the diagram]. See Figure 5.43.
I: [Apparently the black dot is oxygen]. Why are you writing down `oxygen'? Why oxygen in water?
L1: I know inside the water has oxygen.

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
L2: Draw ah? How to draw?
I: Just draw what you think you can `see'.
L2: Hah! Draw a microscope ah?
I: No, just draw a beaker and what you think you can `see' inside the beaker.
L2: [Drawing, but drawing shows `atoms of water']. See Figure 5.44.
L2: [Pointing at Figure 5.44 and asking]. Something like this??
I: [Pointing at the particles inside the beaker]. What are all these?
L2: Atoms.
I: Atoms of what?
L2: Atoms of water.
I: So you think water is made up of atoms?
L2: [participant appeared confused and unsure]
I: [Pointing at the wavy lines inside the beaker and asking]. What are all these?
L2: Hah?
I: Do you want to explain your diagram to me or label anything?
L2: [Draw one of the particles but writing down `atoms of water']. See Figure 5.44.

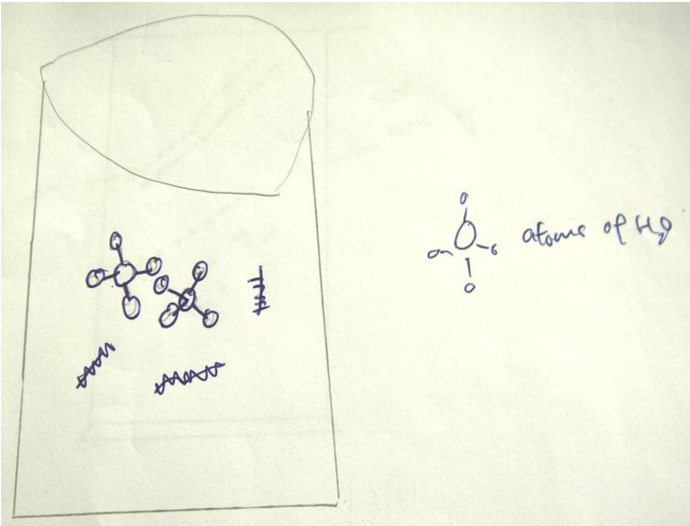


Figure 5.44: L2f

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
L3: Got many molecules.
I: Can you show by drawing?
L3: [Drawing]. See Figure 5.45.
I: Can you explain your drawing?
L3: Got many molecules.
I: Molecules of what?
L3: [Pause]. Water
I: Do you want to draw some more of this? [Pointing to a molecule of water]
L3: [Drawing more of water molecules]. See Figure 5.45.

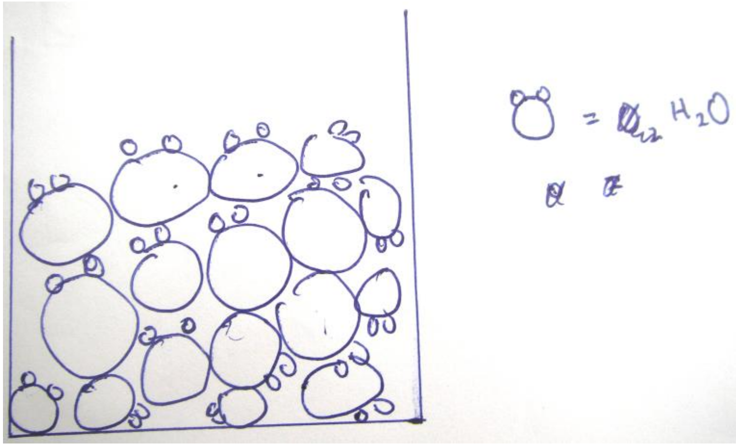


Figure 5.45: L3e

The Medium group

Submicroscopic representations were used and correct chemical representation of water molecules shown. The participants were aware of the particulate nature of matter as all the 3 drawings show water molecules (see Figures 5.46, 5.47, and 5.48). However, none of the drawing shows arrangement of particles appropriate for a liquid. M1's drawing shows two water molecules. Correct chemical representation of water molecule was used. The term "water molecule" was mentioned during explanation. M2's drawing also shows water molecules using the correct chemical representation. The term "water molecule" was also mentioned during explanation. Although M2's drawing contains more water molecules, the arrangement of particles was still too far apart for a liquid. M3's drawing shows some particles which look like molecules but labelled as "oxygen" (see Figure 5.48). However, he explained that "water contains a lot of water molecules".

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
M1: [Looking and listening, then drawing]. See Figure 5.46.
I: [Pointing at the drawing by the participant on the paper]. Is this what you will see?
M1: I imagine seeing this.
I: Do you want to label anything on your diagram?
M1: [Labelling]. See Figure 5.46.
I: [Pointing to the drawing and ask]. `What is this?' Can you explain the drawing(s)?
M1: Water contains a lot of water molecules.

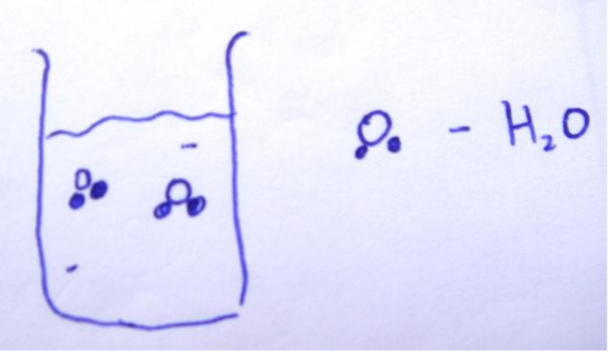


Figure 5.46: M1f

I: [Showing a beaker of water to the participant]. Can you draw to show how a beaker of water might appear when viewed through `a very powerful microscope'?
M2: [Looking and listening, then drawing]. See Figure 5.47.
I: [Pointing at the drawing by the respondent on the paper]. What are all these?
M2: Molecules.
I: Do you want to label anything on your diagram?
M2: [Labelling]. See Figure 5.47.
I: [Pointing to the drawing and ask]. So to you this is water molecule?
M2: Yes.

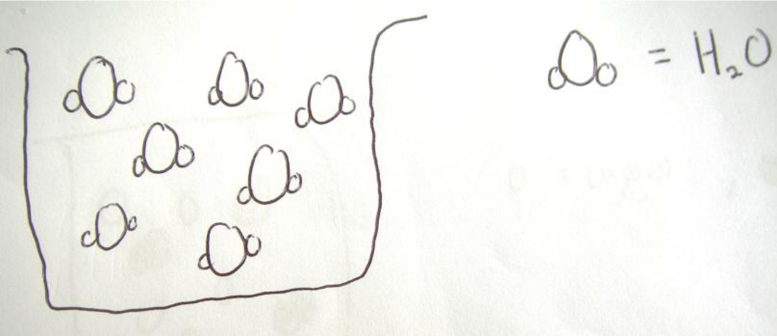


Figure 5.47: M2d

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
M3: [Looking and listening, then drawing]. See Figure 5.48.
I: [Pointing at the drawing by the participant on the paper]. Do you want to label anything?
M3: [Labelling]. See Figure 5.48.
I: [Pointing to the drawing and ask "Can you explain the drawing(s)?"]
M3: A lot of water molecules.

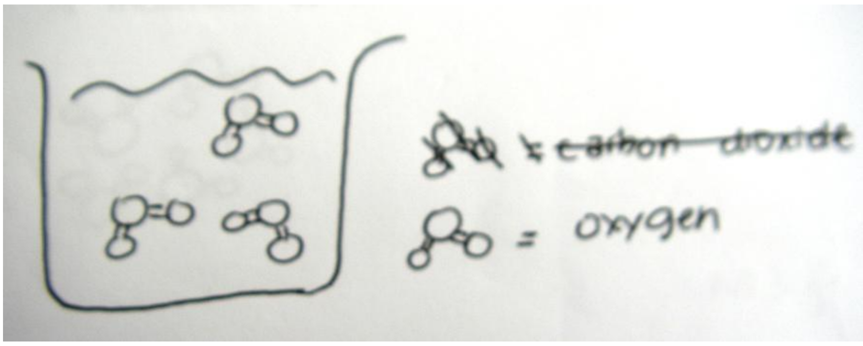


Figure 5.48: M3f

The High group

All the three participants were aware of the particulate nature of matter and had a microscopic view of water. Submicroscopic representations of water were generated using the correct chemical representation of the water molecule. However, only H1 showed chains of water molecules and mentioned hydrogen bonding (Figure 5.49). No respondent showed or mentioned about movement of the particles. H1's drawing shows chains of water molecules. However, the sizes of the atoms within the water molecule, H_2O, do not depict that of the H atom and the oxygen atom (see Figure 5.49). Both H2's and H3's drawings (Figures 5.50 and 5.51 respectively) show water molecules using the correct chemical representation. However, sizes of the hydrogen atom and the oxygen atom are not consistent and the water molecules were too far apart to be in the liquid state.

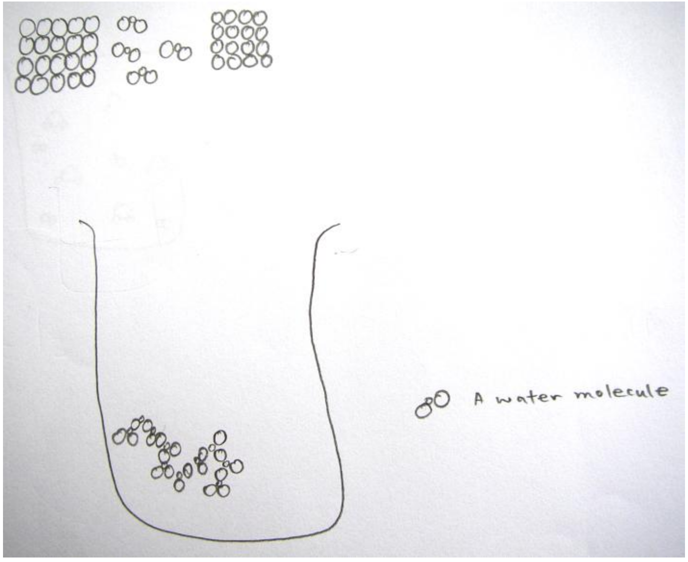


Figure 5.49: H1e

I: [Showing a beaker of water to the participant]. Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
H1: Powerful microscope means … at what level of magnification?
I: You can see at the particulate level.
H1: [Drawing]. Drawing shows wall of beaker as well! See Figure 5.49.
H1: [Pointing to the diagram that was just drawn and explaining]. This is the wall of the beaker. It is a solid.

I: You can just focus on the content i.e. the water inside the beaker only.
H1: [Appeared puzzled but said nothing]
I: [Repeat question to the participant]. Show, by drawing what you can see when a beaker of water is viewed through a very powerful microscope.
H1: You mean what do the particles look like?
I: Yes. Just draw what you can `see' or visualize.
H1: [Drawing and explaining while pointing to the diagram]. There are chains and chains of water molecules like this. There are separate water molecules but not really far apart as water is a liquid. This is the hydrogen bond. See Figure 5.49.
I: Anything else you want to add in?
H1: Should I add in the hydrogen bond?
I: You can draw what you think is important.

I: Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
H2: What is meant by `a very powerful microscope'?
I: You can see the particles.
H2: So what should I draw?
I: Just draw what you think can be `seen' through the powerful microscope.
H2: [Drawing]. See Figure 5.50.
I: Would you like to explain your drawing?
H2: I think no need to explain.

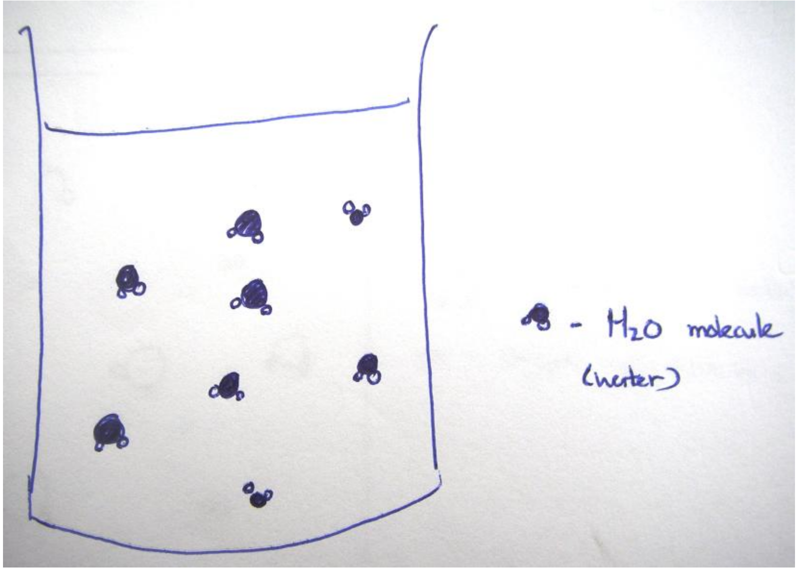


Figure 5.50: H2f

I: [Showing a beaker of water to the participant]. What do you think made up this beaker of water?
H3: Particles.
I: Can you show, by drawing, how a beaker of water might appear when viewed through `a very powerful microscope'?
H3: [Drawing and labelling. Drawing shows the glass wall of the beaker as well].
I: You can just focus on the content i.e. the water inside the beaker.
H3: [Erasing and continue to draw]. See Figure 5.50.
I: [Pointing to the molecules in Figure 5.50]. Do you want to explain anything on your diagram?
H3: [Labelling the diagram and writing something next to the diagram]. See Figure 5.50.

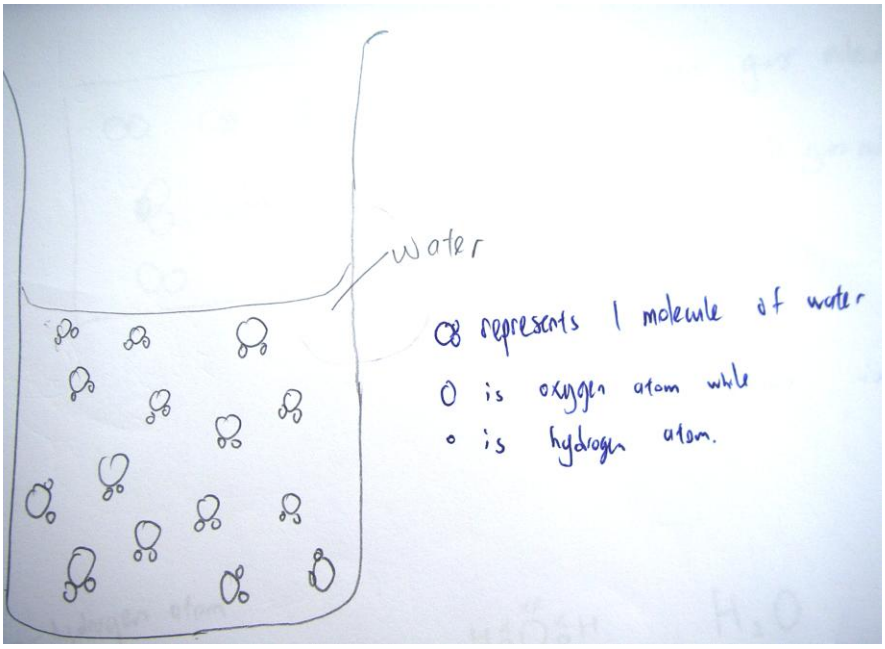


Figure 5.51: H3f

Question 2 – A copper wire or copper foil

To generate the correct representation, participants need to know that copper is a pure substance (an element), the type of particles that make up copper, and that copper is a solid at room condition.

<u>The Low group</u>

Participants in this group still hold a macroscopic view of matter and tend to focus more on the surface features of a substance or a phenomenon. Their limited knowledge of common substances and their weak understanding of basic chemical concepts disabled their ability to generate a representation of a certain concept.

L1 drew a piece of copper foil and a piece of sand paper next to it. He also wrote beside the piece of sand paper the words `make by sand' (see Figure 5.52), and asked if copper is made of iron. L2 drew a piece of sand paper and a strip of copper with some dark shading beside it, which he said is dirty powder after cleaning the copper with sand paper (see Figure 5.53). He had heard of the term `element' but not sure if copper is an element. He probably does not know the meaning of `element'. Only L3's drawing show a piece of copper foil with many small circles inside (see Figure 5.54). He wrote `=Cu' beside a small circle and said the small circles are atoms.

I: [Showing a piece of copper foil]. Can you tell me what are inside this copper wire or copper foil or what is this copper foil made up of?
L1: Is it the thing that we cleaned with sand paper?
I: [Showing the piece of copper foil again]. Yes, this one.
L1: [Looking at the piece of copper and thinking]
I: What do you think is inside the piece of copper foil? Can you use drawing to show or describe what you `see'?
L1: [Drawing, but only a piece of copper strip appeared on the paper]. See Figure 5.52.
I: Do you want to draw anything else?
L1: [Drawing a piece of sand paper next]. See Figure 5.52.
I: Do you want to label anything?
L1: [Writing beside the piece of sand paper these words `make by sand']. Figure 5.52.
I: Anything else that you want to draw or write?
L1: Can it be made of iron?
I: Why iron? Copper is an element. Iron is another element...Why do you think copper is made of iron?
L1: [Participant appeared puzzled but remained silent]

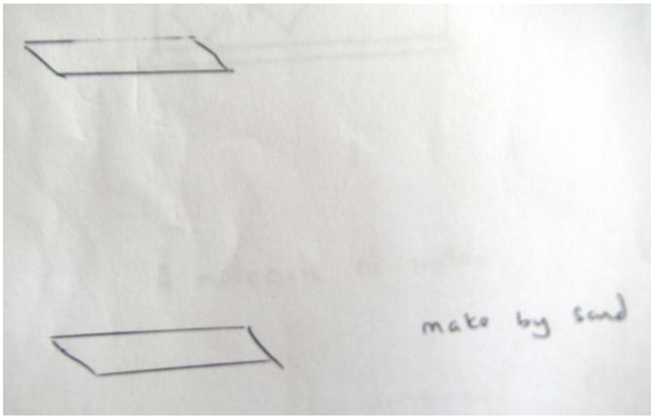


Figure 5.52: L1e

I: [Showing a piece of copper foil]. Can you tell me what are inside this copper wire or copper foil or what is this copper foil made up of?
L2: Hah!
I: Just draw what you think is inside this piece of copper.
L2: [Drawing a piece of sand paper and a strip of copper instead]. See Figure 5.53.
I: What do you think is inside the piece of copper?
L2: Iron.
I: Iron inside the copper foil?? Is copper an element?
L2: [No response]
I: Have you heard of the term `element'?
L2: Yes.
I: Is copper an element?
L2: No, [pause]. Not sure.

I: Do you want to label anything?
L2: [Writing/label `sand paper' and `copper']. See Figure 5.53.
I: What is this? [Pointing at some dark shadings in Figure 5.53]
L2: Something after cleaning the copper with sand paper.
I: Anything else that you want to write or label?
L2: No.

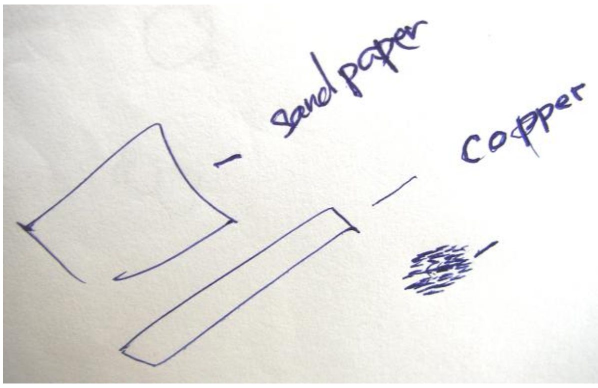


Figure 5.53: L2g

I: [Showing a piece of copper foil]. Can you tell me what are inside this copper foil or what is this copper foil made up of?
L3: Don't know.
I: Can you use drawing to show or describe what you `see'?
L3: [Drawing, but only a piece of copper foil appeared on the paper]. See Figure 5.54.

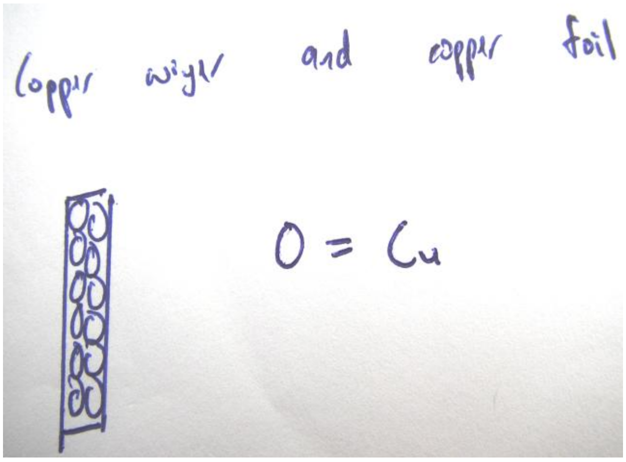


Figure 5.54: L3g

I: What do you think is inside the piece of copper foil?
L3: Inside?? [Pause]. I cannot think. Don't know how to draw.
I: Just draw what you think are inside this strip of copper.
L3: [Drawing many small circles]. See Figure 5.54.
I: [Pointing to the small circles]. What are all these?
L3: Atoms.
I: Do you want to label anything?
L3: [Writing `= Cu' beside a small circle]. See Figure 5.54.
I: Anything else that you want to draw or write?
L3: No.

The Medium group

Generally, the participants in this group know the common substance `copper', had a microscopic view of matter and the type of particles (atoms) for a pure element is correctly depicted. However, they were either not aware of, or not bothered with the arrangement of particles in a solid like copper.

After much prompting, M1 managed to draw many small circles which he said are copper atoms, but he only labelled as Cu. The circles were rather far apart and did not depict the arrangement of particles in a solid (see Figure 5.55). M2 said copper wire or copper foil is made up of many copper atoms. His drawing shows rows of copper atoms (see Figure 5.56). Even after a long pause, M3 was unable to tell what were inside the copper wire/foil and could not draw to show or describe either.

I: [Showing a copper wire]. Can you tell me what are inside this copper wire?
M1: Many particles.
I: What type of particles do you think is inside the piece of copper?
M1: I think is atom.
I: Can you use drawing to show or describe what you `see'?
M1: [Drawing and saying]: `there are many copper atoms'. See Figure 5.55.
I: But you only draw one atom? So, do you think there is only one atom or many atoms?
M1: Many atoms.
I: Then can you draw and show me?
M1: Drawing more and more atoms inside a rectangular box.

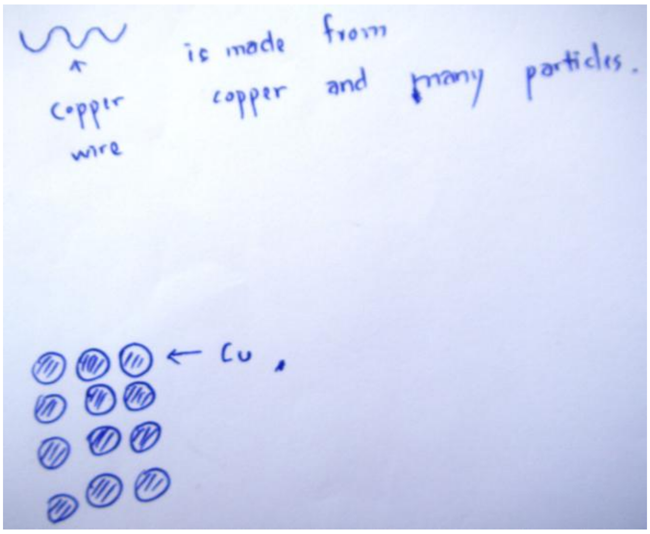


Figure 5.55: M1g

I: [Showing a copper foil]. Can you tell me what is this copper foil made up of?
M2: Made up of many atoms – smaller particles.
I: What type of atoms?
M2: Copper atoms.
I: Can you use drawing to show or describe what you `see'?
M2: You only draw 1 atom of copper or many atoms?
I: Draw what you can `see' or visualize.
M2: [Drawing]   Insert!   Something like this?
I: Do you want to label anything?
M2: [Labelling]. See Figure 5.56.
I: Ok. Good.

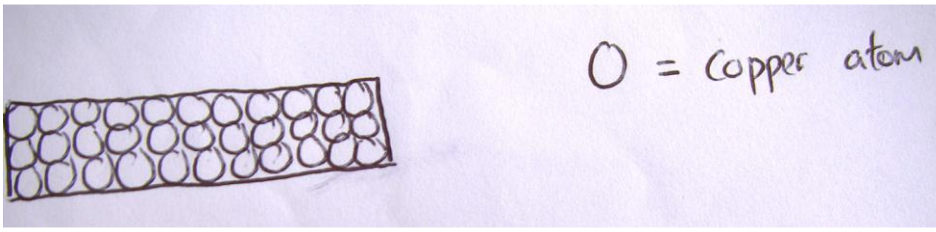


Figure 5.56: M2e

I: [Showing a copper wire]. Can you tell me what are inside this copper wire or what is this copper wire made up of?
M3: [Long pause]
I: Can you use drawing to show or describe what you `see'?
M3: [Thinking for a very long time but did not manage to draw any diagram]
I: Just draw what you think you can `see' or are inside this piece of copper wire.
M3: Can I skip this part?
I: Ok. You can leave a space first.
[M3 was still unable to say or draw anything at the end of the interview].

The High group

All the participants in this group had both a macroscopic and a microscopic view of matter. They knew the substance `copper' very well, that it is a pure substance and an element. The type of particle (atoms) were correctly identified and depicted as submicroscopic representations. Their drawings show arrangement of particles appropriate for a solid (see Figures 5.57, 5.58, and 5.59).

I: [Showing a copper wire and a copper foil]. Can you tell me what are inside this copper wire or copper foil?
H1: Copper atoms.
I: Can you use drawing to show or describe what you `see'?
H1: [Drawing]. See Figure 5.57.
H1: Do I need to show the electron?
I: You want to show the sea of electrons? Show the metallic bond?
H1: Yes.
I: [Pointing to Figure 5.57 and asking]. Why are you leaving a gap here?
H1: Because it is one of the properties of metal. Metals are malleable, ductile, …

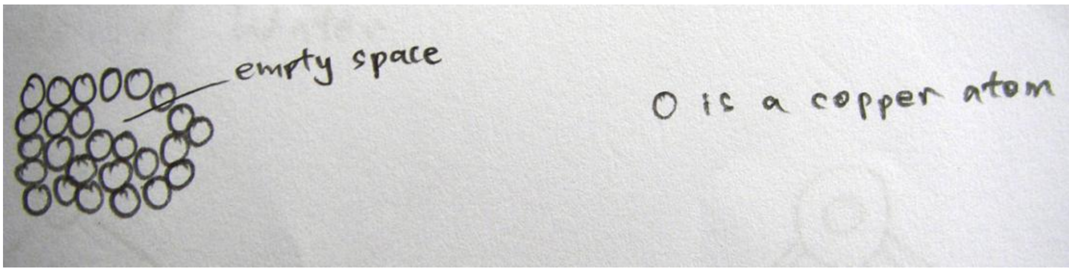


Figure 5.57: H1f

I: [Showing a copper wire and a copper foil]. Can you tell me what are inside this copper wire or copper foil?
H2: Copper atoms.
I: Can you use drawing to show or describe what you `see'?
H2: [Drawing and labelling]. See Figure 5.58.
I: Ok, good.

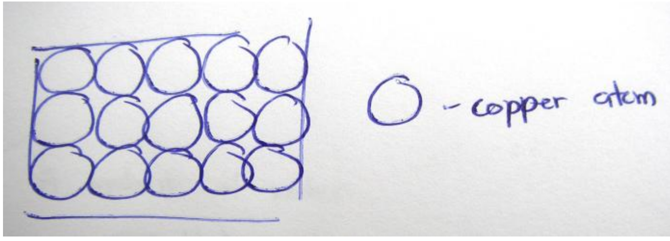


Figure 5.58: H2g

I: [Showing a copper wire and a copper foil]. Can you tell me what are inside this copper wire or copper foil?
H3: Atoms.
I: Can you use drawing to show or describe what you `see'?
H3: What should I draw?
I: Just draw what you think is/are inside this copper wire/foil.
H3: [Drawing and labelling]. See Figure 5.59.
I: Would you like to describe or explain your drawing?
M3: I think no need to explain.

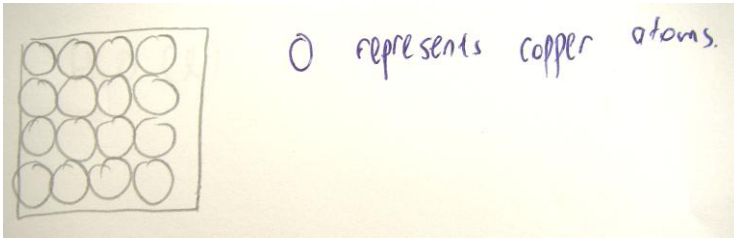


Figure 5.59: H3g

Question 3 – A mixture of carbon dioxide and oxygen gas

To generate the representations correctly, participants must understand the concept `mixture', know that both carbon dioxide and oxygen are gases at room condition, that carbon dioxide is a compound while oxygen is an element, as well as the type of particles that make up carbon dioxide and oxygen respectively.

The Low group

L1's drawing shows two different types of `circles' (Figure 5.60). He drew the different types of `circles' next to the drawing and wrote down the words `oxygen' and `carbon dioxide'. Surprisingly, L1 was the only participant who explained that the particles (referring to the `circles') will move, and showed using arrows and explaining the movement (see excerpt from the interview transcript below). L2 drew something that looked like tiny circles (after much prompting), and writing down `some gas', beside the tiny circles, and another label `see nothing' (see Figure 5.61). L3's drawing shows two different types of particles. The participant drew the particle that looks like a molecules beside the drawing and wrote down `$=CO_2$'. He also wrote `$=O_2$' beside the particle that looks like an atom, O, after much prompting (Figure 5.62). The molecule `$=CO_2$' is not correctly represented. The representation also does not depict that of a mixture of gases, as the arrangement of particles is too close.

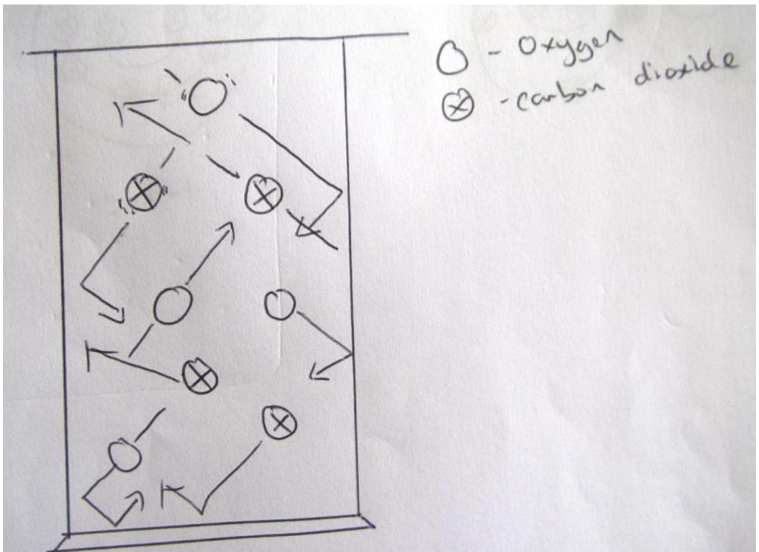


Figure 5.60: L1f

I: If I give you a closed gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
L1: [Pause]
I: Can you use drawing to show your answer?
L1: A mixture?
I: Yes. Maybe you just draw a closed gas jar first. Then draw what you think you can `see' inside the gas jar.
L1: [Began drawing on the plain paper provided. Drawing shows two different types of circles]. See Figure 5.60.
I: Do you want to label your drawing?
L1: [Participant drew the 2 different types of circle beside the drawing and wrote down the words `oxygen' and `carbon dioxide']
I: Can you explain your drawing?
L1: The particles will move.
I: How will they move?
L1: [Showing using arrows and explaining the movement].
I: Good. I like the part about the movement of particles.

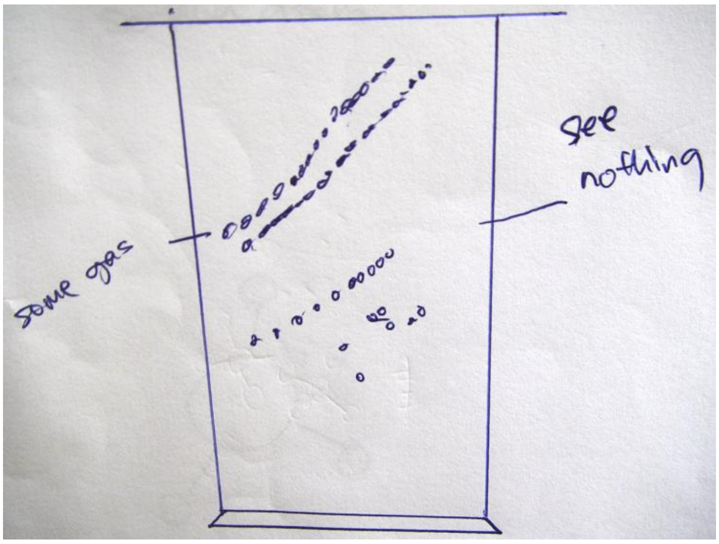


Figure 5.61: L2h

I: If I give you a closed gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
L2: What is gas jar?
I: [Showing a gas jar to the participant]. Can you draw a gas jar with a cover?
L2: [Drawing a gas jar but no cover]. See Figure 5.61.
I: Now, draw what you can `see' inside the gas jar.
L2: See nothinglah…
I: Why nothing?
L2: Can't see gas.
I: Why see nothing? Imagine you see through a very powerful microscope.
R: Because gas go away already…
I: But the gas jar is closed.
L2: Haa! Like that ah?
I: Just draw what you think you can `see' through the microscope.
L2: I've seen leaf before. But I never see gas.
I: Can you just draw something that you think you may be able to `see'?
L2: [Drawing something that look like tiny circles]. See Figure 5.61.
I: Do you want to label your drawing?
L2: [Writing down `some gas' beside the tiny circles and another label `see nothing']. See Figure 5.61.

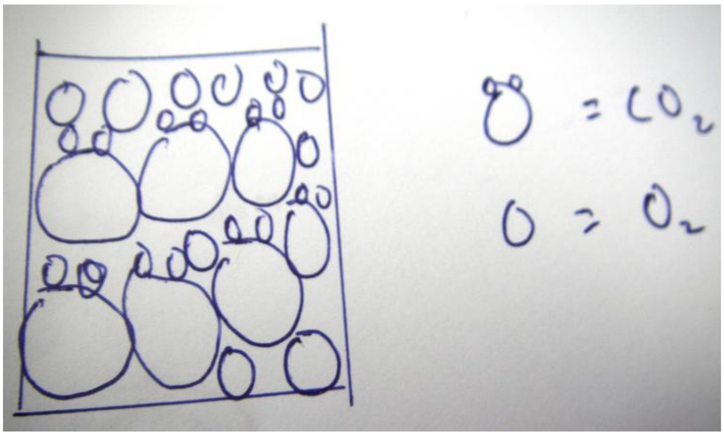


Figure 5.62: L3h

I: If I give you a closed gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
L3: [Silence]
I: Can you draw a gas jar first?
L3: [Drawing a gas jar but it is not closed]
I: A closed gas jar?
L3: [Participant drawing a line across, on top of gas jar]
I: So, what are you going to draw inside the gas jar?
L3: A mixture?
I: Yes, a mixture of carbon dioxide and oxygen gas.
L3: [Began drawing on the plain paper provided. Drawing shows 2 different types of particles]. See Figure 5.62.
I: Do you want to label your drawing?
L3: [Participant drew the particle that looks like a molecule beside the drawing, then wrote down `=CO_2']. See Figure 5.62.
I: [Pointing to the particle inside the gas jar that looks like a molecule]. Does this represent carbon dioxide?
L3: Yes.
I: How about oxygen?
L3: [Participant then wrote `=O_2' beside the particle that looks like an atom]

<u>The Medium group</u>

Microscopic terms such as molecules are missing in the diagram and in the conversation/explanation (M2, M3). Generally, the chemical representations used are not appropriate (M1, M2).

M1's drawing shows only one molecule of oxygen and one molecule of carbon dioxide, with the oxygen molecule looking like an atom. When prompted, M1 continue to draw more and more such particles (see Figure 5.63). M1 drew all the O_2 molecules at the bottom of the gas jar and CO_2 molecules on top, but did not know or could not explain why. M2's drawing (Figure 5.64) shows two different types of particles which he labelled as O=oxygen and OO=carbon dioxide. The chemical representations for O_2 and CO_2 were wrong. The depiction for O_2 looks more like an atom, and the molecule CO_2 only contains 2 atoms. M3's drawing (Figure 5.65) shows 5 molecules each of O_2 and CO2, but he wrote O=O = oxygen, and CO_2=carbon dioxide, instead of oxygen molecules and carbon dioxide molecules respectively. This shows M3 could not distinguish between the macroscopic and the microscopic worlds of matter.

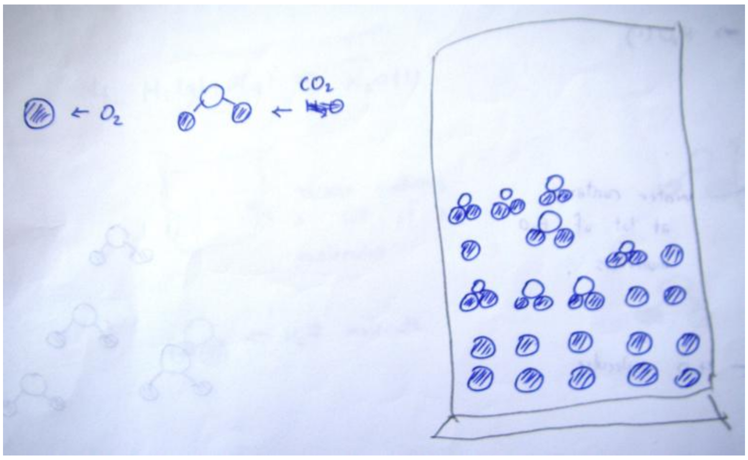


Figure 5.63: M1h

I: If I give you a closed gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
M1: [No response]
I: Can you use drawing to show your answer?
M1: [Began drawing on the plain paper provided]. Drawing shows only 1 molecule of oxygen and 1 molecule of carbon dioxide (labeled so), with the oxygen molecule looking like an atom. See Figure 5.63.
I: You only see this?
M1: Continue to draw more and more such particles (Figure 5.63)

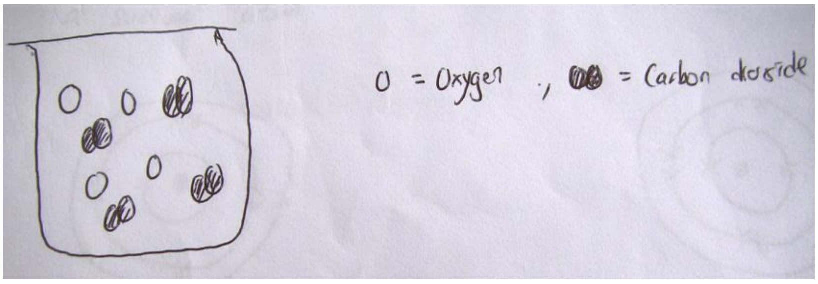


Figure 5.64: M2f

I: If I give you a closed gas jar containing a mixture of carbon dioxide and oxygen gas, what are you likely to `see' through a very powerful microscope?
M2: [Long silence, apparently thinking about the question] Can I draw?
I: Yes, you can use drawing to show your answer.
M2: [Began drawing on the plain paper provided]. See Figure 5.64.
I: [Pointing at the a small circle on Figure 5.64]. Is this oxygen?
M2: [Labelling] see Figure 5.64.
I: Anything else you want to label?
M2: No.

I: If I give you a gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
M3: [Long pause, then slowly drawing something. Participant began drawing a gas jar, with molecules inside, on the plain paper provided. Drawing shows 5 molecules of oxygen and 5 molecules of carbon dioxide. See Figure 5.65.
I: Can you label or write down what the drawing represent?
M3: [Writing something]. See Figure 5.65.
I: [Participant saw some mistakes with his drawing earlier (see Figure 5.65) and made some changes but he made another mistake in the process]

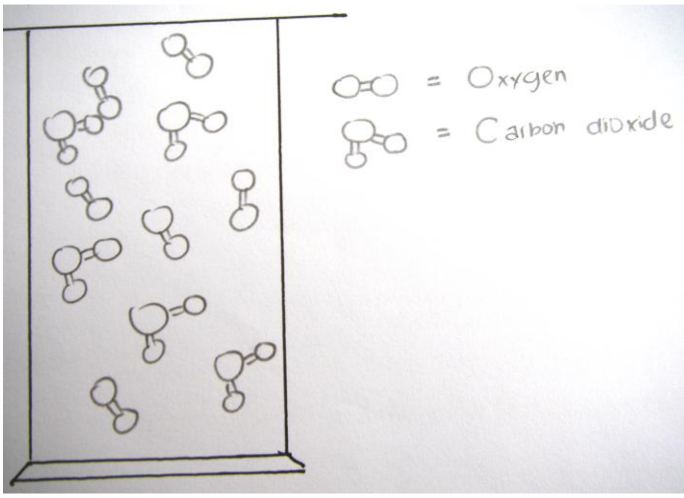


Figure 5.65: M3e

The High group

All the participants in this group used the correct chemical representations to depict the oxygen molecules (an element) and carbon dioxide molecules (a compound). Microscopic terms such as `molecules' were used. Arrangement of particles shown is appropriate for a mixture of gases. However, only H1 mentioned about the gas particles moving at random, but did not show any movement in the diagram. See Figures 5.66, 5.67, 5.68, and excerpts from the interview transcripts.

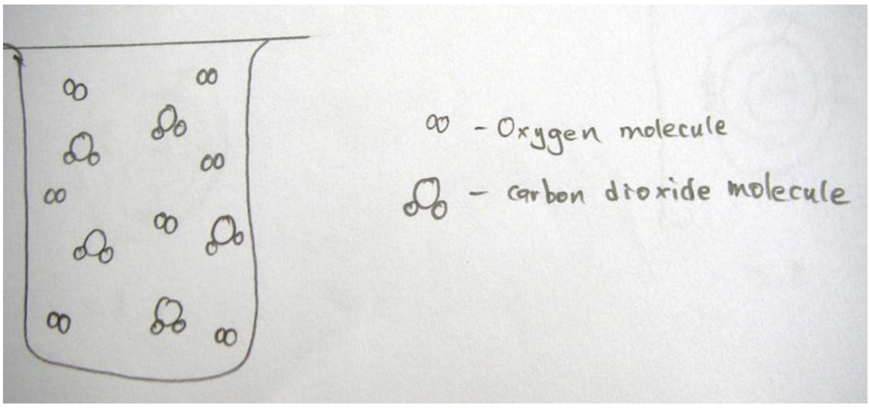


Figure 5.66: H1g

I: If I give you a gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
H1: [Busy drawing on the plain paper provided]. See Figure 5.66.
I: Can you explain your drawing?
H1: Since it is a mixture, the particles are all thoroughly mixed. The particles are quite far apart as both are gases. They are moving at random. Carbon dioxide molecules are heavier compared to oxygen molecules so more are sinking or stay at the bottom.

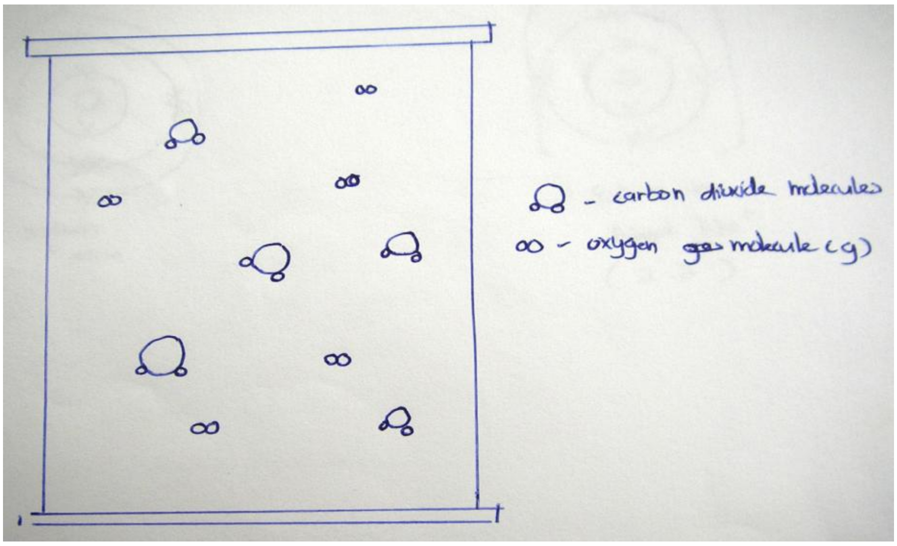


Figure 5.67: H2h

I: If I give you a gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
H2: [Busy drawing on the plain paper provided]. See Figure 5.67.
I: Can you explain your drawing?
H2: [Pointing to Figure 5.67]. These are carbon dioxide molecules and these oxygen molecules.
I: Can you label your drawing?
H2: [Labelling]
I: Why do you write carbon dioxide molecules but oxygen gas?
H2: [Change the word `gas' to molecule].

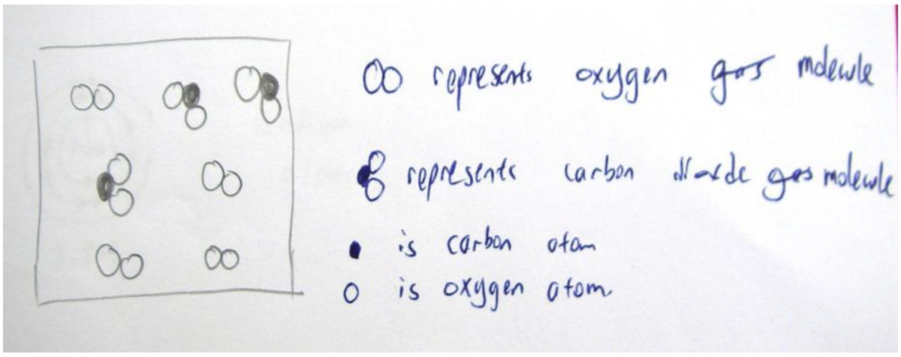


Figure 5.68: H3h

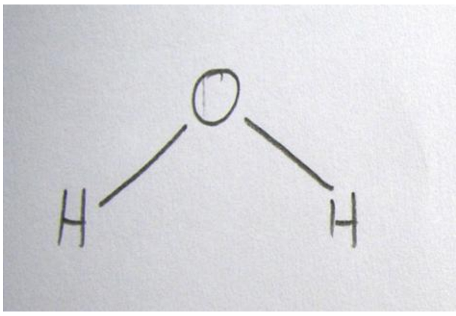
I: If I give you a gas jar containing a mixture of carbon dioxide and oxygen gas. What are you likely to `see' through a very powerful microscope?
H3: [Busy drawing on the plain paper provided. Participant wrote oxygen gas and carbon dioxide gas]. See Figure 5.68.
I: Do you want to label as oxygen gas or oxygen molecule?
H3: [Cancel oxygen gas, wrote oxygen molecule].

Question 4 – How to represent "a molecule of water"?

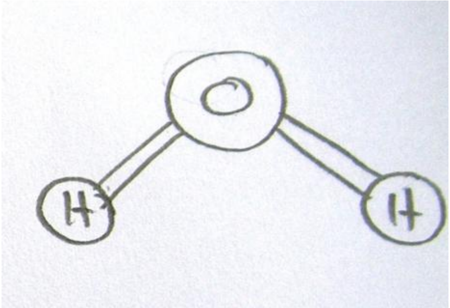
Participants must be able to distinguish between a one-particle and a many-particle system in order to generate the correct representation.

A total of seven different correct representations of the water molecule were generated by the participants. The High group generated seven different representations of the water molecule (Figure 5.69), the Medium group managed to draw two correctly (Figure 5.70), while the Low group only came out with one correct representation - the space-filled model (Figure 5.71). As the participants were beginning students in chemistry, their ability to represent `a water molecule' can be considered good.

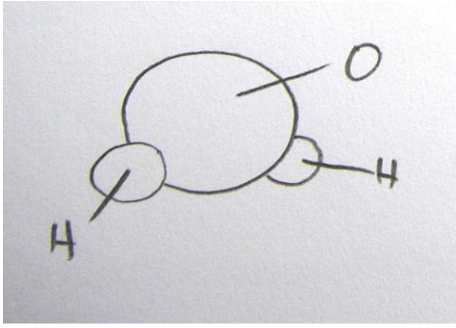
The space-filled model appears to be the most common representation of the water molecule among the participants. This representation was generated by all the three groups and by seven of the nine participants. This is probably because this representation often appears in most chemistry text and the teaching courseware. Surprisingly, the simplest and the most commonly used representation (H_2O), was only shown by three of the participants. Perhaps, students only know H_2O as a chemical formula, without realising that chemical formula is an example of a symbolic representation.



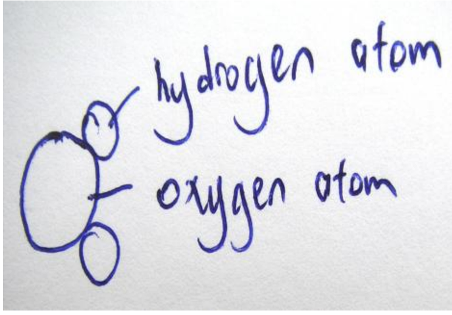
(a) Structural formula



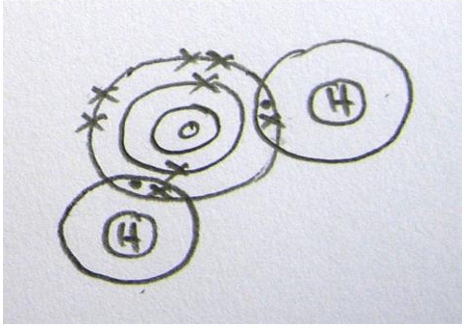
(b) Ball-and-stick model



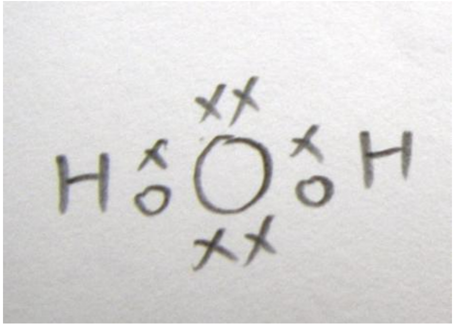
(c1) Space-filled model



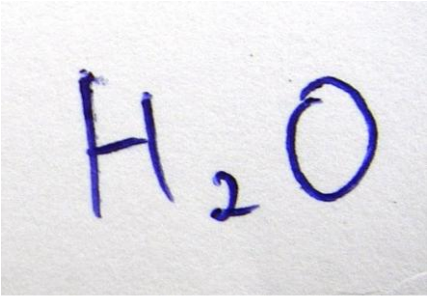
(c2) Space-filled model



(d) Electron-dot representation



(e) Lewis structure



(f) Molecular formula

Figure 5.69: Different representations of the water molecule by the High group

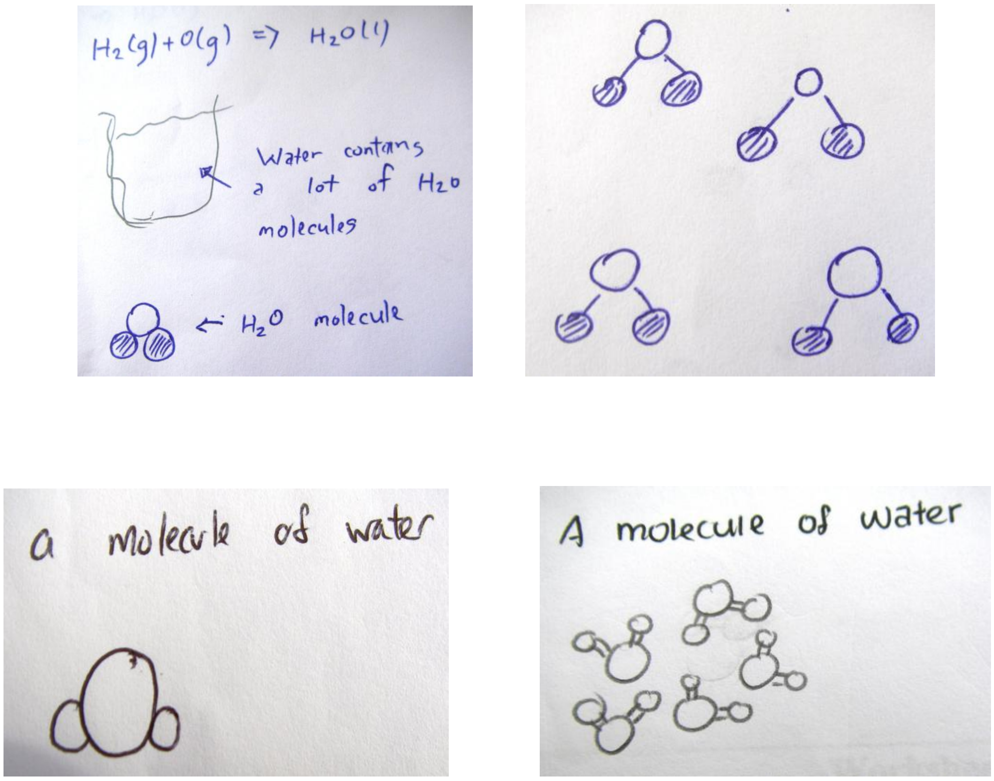


Figure 5.70: Different representations of the water molecule by the Medium group

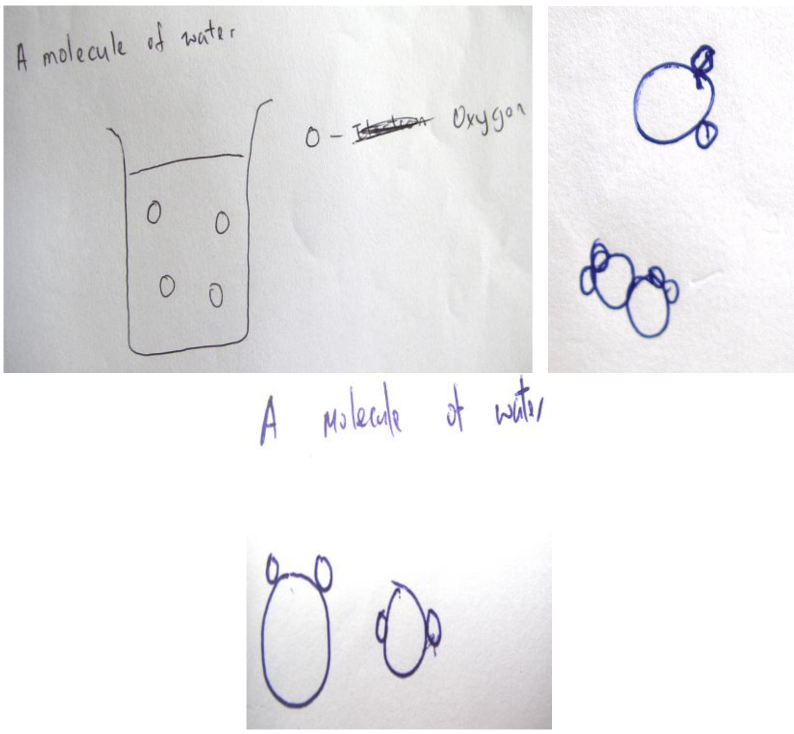


Figure 5.71: Different representations of the water molecule by the Low group

The Low group

Although the question emphasizes "a molecule of water", L1 drew a beaker of water showing a few small circles which he labelled as `oxygen' (Figure 5.72). L2 drew 2 different particles (Figure 5.73), while L3 drew 2 similar particles of different sizes (Figure 5.74).

I: Can you show, in as many ways as you could, how you would represent a molecule of water.
L1: [Participant did not seem to get the question]
I: [Repeat the question to the participant and emphasize the term `a molecule of water']. How would you show by drawing?
L1: [Pause then asking question]. Is it mineral water?
I: Just a molecule of water. I want to emphasize this: `a molecule of water'.
L1: [Draw a beaker and some circles inside the beaker]. (Figure 5.72)

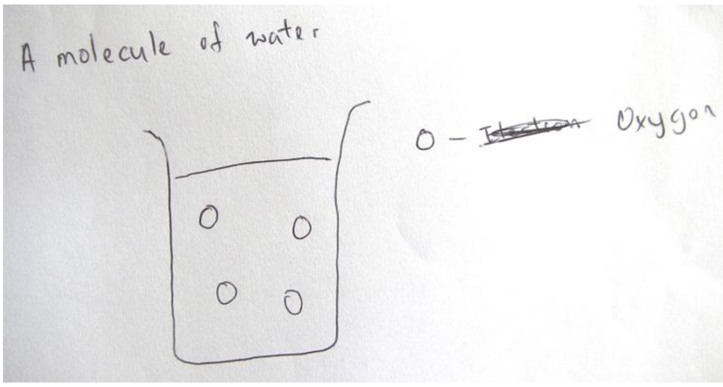


Figure 5.72: L1h

I: [Pointing to Figure 5.72]. What do the circles represent?
L1: Electrons.
I: To you, they represent electron?? We're talking about a molecule of water!
L1: Inside the water has some atoms. [Then writing O – oxygen]. See Figure 5.72.
I: Why did you write or draw oxygen?
L1: [Appeared confused and not knowing what to do next].

I: Can you show me how you would represent a molecule of water?
L2: [Drawing a space-filled model of a water molecule]. See Figure 5.73 (upper part of diagram).
I: Only this one? Is there any other way to show a molecule of water?
L2: No.
I: Are you sure there is no other way to represent a molecule of water?
L2: Not sure.
I: Can you try drawing another one?
L2: [Drawing 2 molecules of water joined together]. See Figure 5.73 (lower part of diagram).
I: Why are you drawing the 2 water molecules joined together?
L2: Don't know.

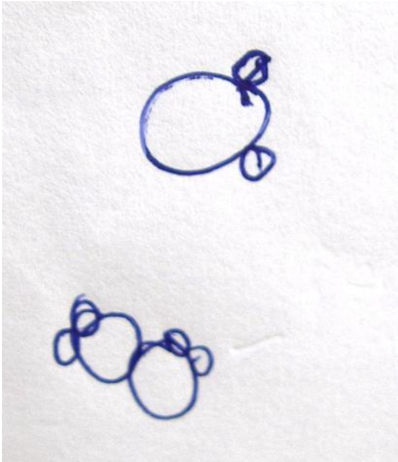


Figure 5.73: L2i

I: How would you represent a molecule of water?
L3: [Participant did not seem to understand the question]
I: [Repeat the question to the participant and emphasize the term `a molecule of water']. How would you show by drawing?
L3: [Drawing]. See figure 5.74.
I: Anything else that is different but still represents or means a molecule of water?
L3: [Drawing another similar molecule]. No more.
I: But these two molecules are the same! I want to emphasize the term `a molecule of water'. [Pointing at the molecules] See Figure 5.74.

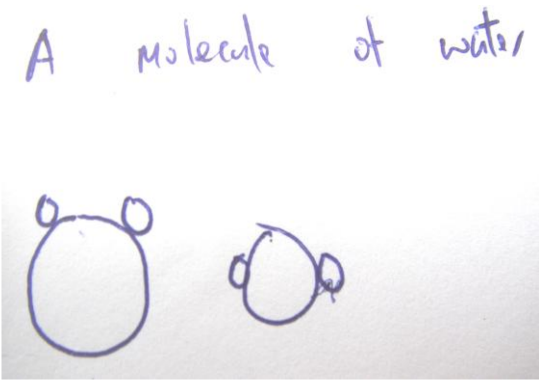


Figure 5.74: L3i

The Medium group

Both M1 and M3 drew several molecules of water but M1 manage to draw 2 different representations (Figures 5.75 and 5.76). Only M2 drew a spaced-filled model of a water molecule (Figure 5.77).

I: Can you show, in as many ways as you could, how you would represent a molecule of water.
M1: [Participant did not seem to get the question]
I: [Repeat the question to the participant and emphasize the term `a molecule of water']
M1: [Show drawing, H_2O]. (Figure 5.75)

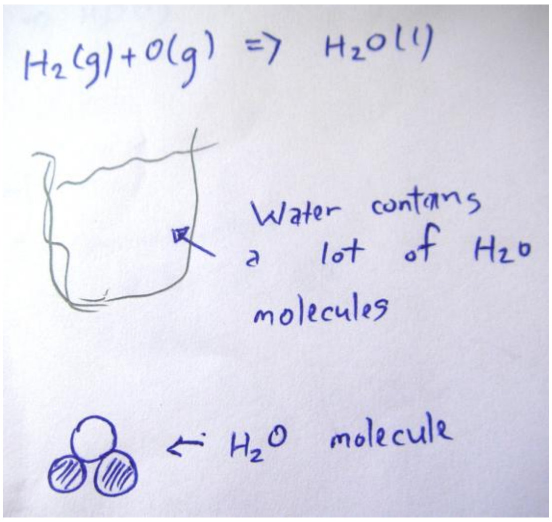


Figure 5.75: M1i

I: Only this? Any other drawing that you want to show?
M1: Still trying… but showing many molecules of water instead. (See Figure 5.76)

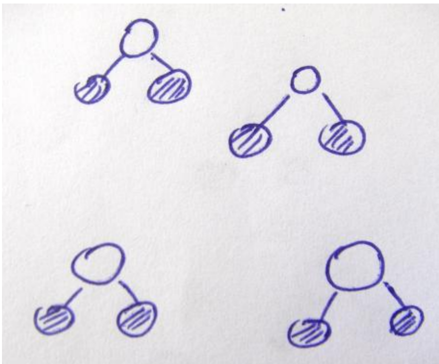


Figure 5.76: M1j

I: Why are you drawing a lot of water molecules? Show me another way you would represent a molecule of water.
M1: [Pointing to H_2O and the ball-and stick model of water]
I: Are all the representations similar? Which one do you prefer to use?
M1: This one, pointing at the symbol \`H_2O'.
I: Why?
M1: Easier to write or draw.
I: Why do you need to use or know so many ways to represent a molecule of water?
M1: I don't know.

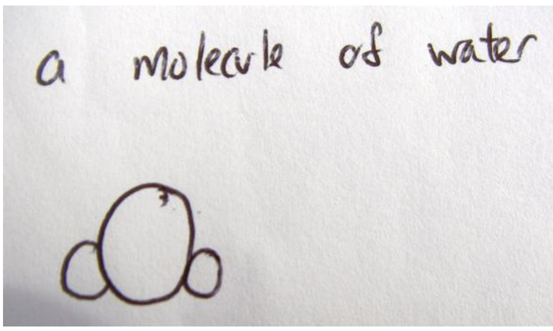


Figure 5.77: M2g

I: Can you show, in as many ways as you could, how you would represent a molecule of water?
M2: [No response]
I: Show on paper how you would represent a molecule of water. [Emphasize the term `a molecule of water']
M2: [Trying to draw something] See Figure 5.77.
I: Ok. This is one of the representations. Any other drawing that you want to show?
M2: No.
I: [Pointing at the drawing in Figure 5.77]. This is the most common representation for water molecule. Is there other representation that you would like to draw?
M2: No more. I only see this one.

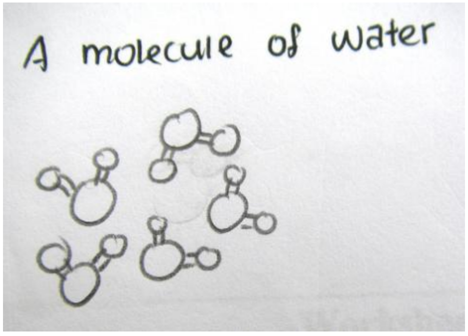


Figure 5.78: M3h

I: Can you show me how you would represent a molecule of water.
M3: [Participant did not seem to get the question]
I: [Repeat the question to the participant and asking him to write down the term `a molecule of water']
M3: [Writing]
I: How would you show how a molecule of water looks like?
M3: [Taking a long time to draw … but drawing a few molecules of water instead]. See Figure 5.78.
I: Any other way you can represent a molecule of water?
M3: [Thinking hard but could not come out with anything else]

<u>The High group</u>

H1 showed four different representations of the water molecules but missed out on the simplest representation – H_2O. H2 showed three different representations but included H_2O (Figure 5.80). H3 only showed two different representations and managed to produce a third one, H_2O, upon prompting. H3 went on to write another representation, H_2O (l), which does not represent a molecule of water but water itself. See Figure 5.81.

I: Can you show, in as many ways as you could, how you would represent a molecule of water?
H1: [Began drawing].
I: Ok. One, …, anymore?
H1: Can I draw the whole molecule?
I: Yes, keep drawing.
H1: [Continue drawing]. See Figure 5.79.

I: You always see water molecules in the teaching courseware. How do they look like?
H1: Can't recall.
I: Any other way to represent a molecule of water?
H1: [Drawing another one – the spaced-filled model, followed by another]. See Figure 5.79.
I: Anymore ways to represent a molecule of water?
H1: [Pause]. I think that's all.
I: How about H_2O?
H1: [Appeared surprised that he has missed out this one!]
I: Are all the representations similar? Which one do you prefer to use?
H1: This one, pointing at H_2O
I: Why?
H1: Easier to write and use, for example when writing chemical equation. .
I: Why do you need to use or know so many ways to represent a molecule of water?
H1: Can use different representation for a different purpose?
I: Good. Let's move on.

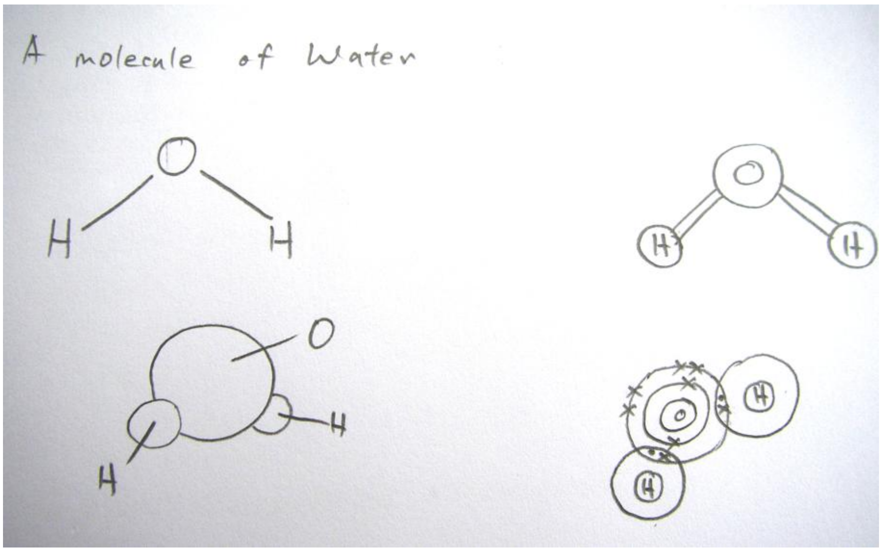


Figure 5.79: H1h

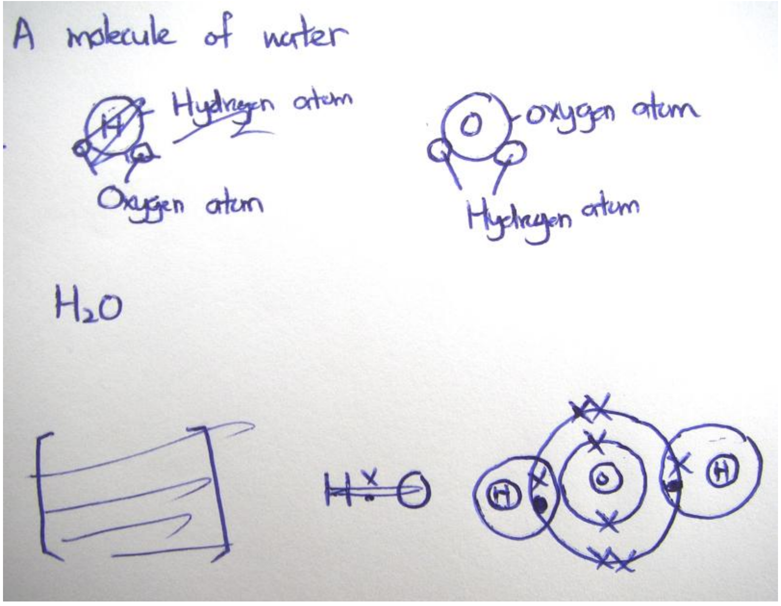


Figure 5.80: H2i

I: Can you show, in as many ways as you could, how you would represent a molecule of water?
H2: How many ways to represent?
I: Yes. You can draw as many ways as you can.
H2: [Began drawing]. See Figure 5.80.
I: Any more you want to show?
H2: [Trying but no new representation appears].
I: Only 3 representations? [Pointing to a ball-and-stick model of water on the table] How about this?
H2: [Looking at the model]
I: Which representation do you prefer to use?
H2: This one, [Pointing at H_2O].
I: Why did you choose that?
H2: Easier to write, e.g. in writing chemical equation.

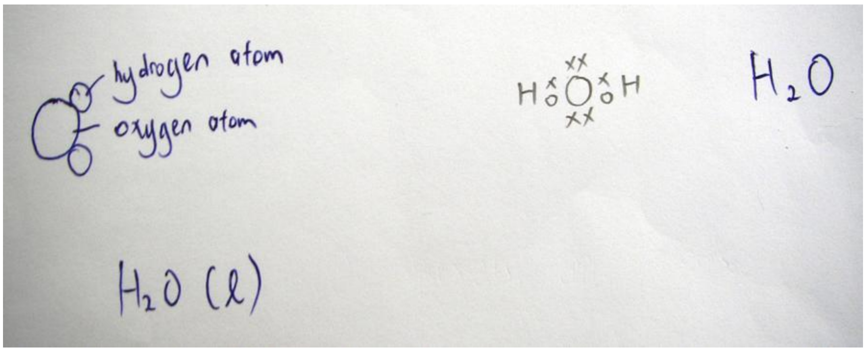


Figure 5.81: H3i

I: Can you show, in as many ways as you could, how you would represent a molecule of water?
H3: [Drawing 2 different representations of a water molecule]. See Figure 5.81.
I: Any other way to represent a molecule of water?
H3: [Thinking but not drawing new representation].
I: Can you recall some other ways to represent water molecule that you always use?
H3: [Trying hard to recall. Finally wrote down H_2O on the paper]. See Figure 5.81.
I: Any more?
H3: No more.
I: How was water molecule represented in the chemistry teaching courseware?
H3: Can't recall.
I: Ok, of the representations that you have drawn or written, which one do you prefer to use?
H3: This one. [Pointing at H_2O] and say: this is the chemical formula of water.
I: Can you tell me why you prefer this representation?
H3: Easier to write.

Question 5 – Electron arrangement of (i) a sodium atom, and (ii) a sodium ion.

In order to generate the correct representations, participants must have knowledge and understanding about the three fundamental particles of matter – atom, molecule and ion, structure of the atom, sub-atomic particles, electron arrangement, valence electron, as well as the concept of ion and charge of an ion.

The Low group

Generally, participants from this group had poor understanding of basic chemical concepts, in particular, the particles of matter – atom, molecule and ion. The sub-atomic particles they need to deal with when drawing the structure of atom and ion added more challenge to this group of participants. Without the knowledge of the structure of atom, electron arrangement of an atom or an ion does not make sense to them. Even if they can draw, it is only a depiction of surface features. They could not appreciate or understand the representations produced. L1 wrote the word `iron' instead of `ion'. He probably does not know the meaning of `ion'. Surprisingly, L1 could draw and describe the electron arrangement of the sodium atom but without prompting, he does not know or aware of the meaning of 2.8.1. L1 could not draw to show `a sodium ion' (see Figure 5.82) and could not tell the difference between sodium atom and sodium ion. L2's drawing shows the sodium atom looking like a molecule (see Figure 5.83). He also could not draw to show `a sodium ion'. L3 could draw to show the electron arrangement of a sodium atom (see Figure 5.84) but he was unsure what `x' on the diagram represents. Excerpts from the interview transcripts provide evidence on this finding. L3 could not draw and show the electron arrangement of a sodium ion. He showed 14e instead of 10e (see Figure 5.84). He also could not tell the difference between a sodium atom and a sodium ion.

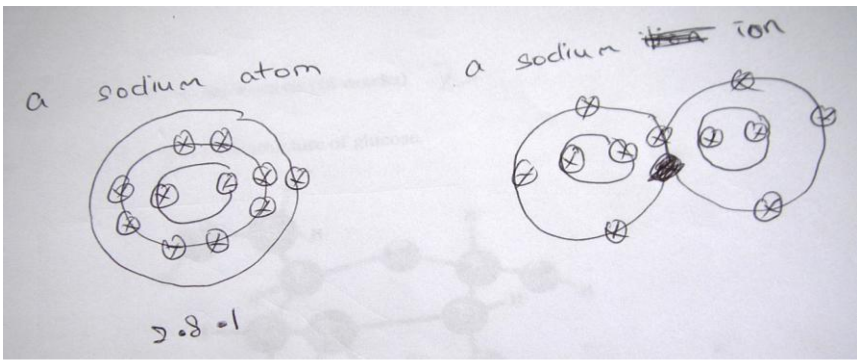


Figure 5.82: L1i

I: Can you write down the words `a sodium atom' and `a sodium ion'?
L1: [Writing but can't spell the word `ion'. Writing down `iron' instead]
I: How do you spell the word `ion'?
L1: Deleted the word `iron' and corrected it to `ion'.
I: Can you draw to show the electron arrangement of a sodium atom?
L1: [Drawing]. See Figure 5.82.
L1: How many electrons?
I: The proton number is 11.
L1: 11 electrons? [Continue to draw]. See Figure 5.82.
I: Now, can you describe the electron arrangement of the sodium atom that you have drawn?
L1: [Respondent writing down 2.8.1]. See Figure 5.82.
I: What do you meant by `2.8.1'?
L1: [Pause]
I: What do the number `2' mean?
L1: [Silence]
I: [Pointing to the symbol that apparently represents electron in Figure 5.82]. What does this symbol represent?
L1: Electrons.
I: So, what do `2.8.1' represent?
L1: 2 electrons, 8 electrons, 1 electron.
I: Right. Can you draw to show the electron arrangement of a sodium ion?
L1: [Drawing. But drawing showed 2 atoms combined, and the atoms are not sodium atoms!]. See Figure 5.82.
I: What do you think is the difference between a sodium atom and a sodium ion?
L1: [No response]

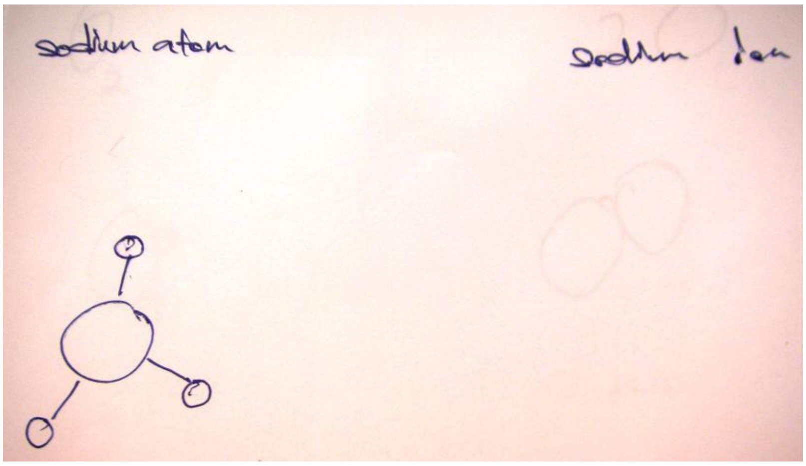


Figure 5.83: L2j

I: Can you write down the words `a sodium atom' and `a sodium ion'?
L2: [Writing]
I: Can you draw to show the electron arrangement of a sodium atom and a sodium ion?
L2: Hah! Draw again ah?
I: Yes, drawing can show and tell more clearly than writing.
L2: Cannot imagine lah.
I: Just draw what you think represent a sodium atom and show the electron arrangement.
L2: [Drawing, but drawing shows something that looks like a molecule]. See Figure 5.83.
I: How about sodium ion? Can you draw to show the electron arrangement of a sodium ion?
L2: Don't know. [Nothing appears on the paper for sodium ion]
I: Do you know the difference between a sodium atom and a sodium ion?
L2: Don't know.

Figure 5.84: L3j

I: Can you write down the words `a sodium atom' and `a sodium ion'?
L3: [Writing down the words correctly on the paper provided]
I: Can you draw to show the electron arrangement of a sodium atom?
L3: Is it 2 point something point something? [Meaning 2.-.-]
I: Ok, just try to draw what you can.
L3: [Drawing]. See Figure 5.84.
I: What are all these? [Pointing to the `x' on the diagram]
L3: [Silence]
I: Are they electrons?
L3: Maybe.
I: How many electrons are there in an atom of sodium?
L3: Nine.
I: A sodium atom has 11e.
L3: [Respondent drawing another shell and added 2 more electrons to the diagram]
I: Can you draw to show how a sodium ion looks like?
L3: [Drawing, but diagram shows 14e]. See Figure 5.84.
I: Why are you drawing 14e?
L3: Because has more sodium atom.
I: Why more electron?
L3: Because extra 3e.
I: Can you describe the electron arrangement of a sodium atom?
L3: [Writing down 2.8.1 and reading at the same time]. 2 point 8 point 1.
I: Can you also describe the electron arrangement of the sodium ion?
L3: [Writing 2.8.4]
I: Why are you writing like that? 2.8.4?
L3: Because I write 14.
I: Why do you write 14? What is the meaning of the number `14'?
L3: I don't know.
I: Can you tell me the difference between a sodium atom and a sodium ion?
L3: [Pointing to the drawing of the sodium atom]. This is atom. [Next, pointing to the other drawing and said]. This is molecule.
I: Why do you say it is a molecule?
L3: More one atom.
I: Can you show me where the other atom is?
L3: [Pointing and showing sodium atom is one atom, and sodium ion is another atom]

<u>The Medium group</u>

Even after a long pause, M1 was unable to draw the electron arrangement of a sodium atom and a sodium ion. Both the sodium atom and the sodium ion look similar (see Figure 5.85). M1 also could not describe their electron arrangement. He does not seem to understand the meaning of the term `electron arrangement'. Actually he did not even know the difference between a sodium atom and a sodium ion. M2 also took a long time to draw but the 2 drawings appear similar (see Figures 5.86 and 5.87). M2 later redrew the diagram but still wrong. He does not understand the meaning of `describe'. After the term was explained to him, M2 could describe the electron arrangement of the sodium atom and the sodium ion. However, he was unsure of the difference between a sodium atom and a sodium ion. M3 took a long time to draw the electron arrangement of a sodium atom and a sodium ion but could not describe the electron arrangement for both particles. He did not know the meaning of electron arrangement, as well as the difference between a sodium atom and a sodium ion (see Figures 5.88). Excerpts from the interview transcript provide evidence on this finding:

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
M1: [Trying hard to draw something]. See Figure 5.85.
I: Can you describe the electron arrangement of the sodium atom and the sodium ion that you have drawn?
M1: [Participant did not seem to know what to do]
I: Do you know the meaning of electron arrangement?
M1: [Not responding]
I: What do you think is the difference between a sodium atom and a sodium ion?
M1: Sodium atom represents an element of sodium. Sodium ion represents the characteristic of an element. [Participant appeared unsure]
I: [Repeat the above question]. You can use drawing to show what you think is the difference between a sodium atom and a sodium ion.
M1: I think the proton number… Not sure… I cannot answer.

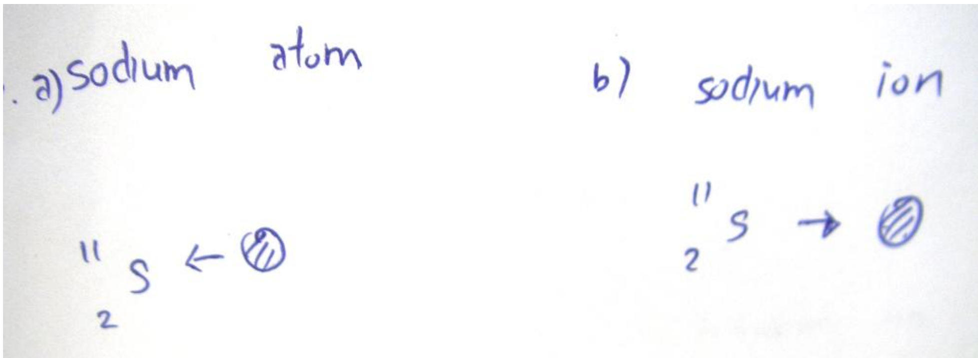


Figure 5.85: M1k

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
M2: Sodium atom and …
I: [Repeat the above question]. Can you draw to show?
M2: [Taking a long time to draw but the two drawings appeared to be similar]. See Figure 5.86.
I: Why are the two drawings the same?
M2: [Redrawing the diagram]
I: How would you describe the electron arrangement of the sodium atom and the sodium ion that you have drawn?
M2: [Participant did not seem to understand the meaning of `describe']
I: Do you know the meaning of electron arrangement?
M2: [Not responding]
I: Can you describe the electron arrangement of the sodium atom?
M2: 2.8.1
I: Can you describe the electron arrangement of the sodium ion?
M2: 2.8 (See Figure 5.86).
I: What do you think is the difference between a sodium atom and a sodium ion?
M2: [Not sure what to say. Participant appeared very confused]. Sodium atom… Sodium ion has positive sign.

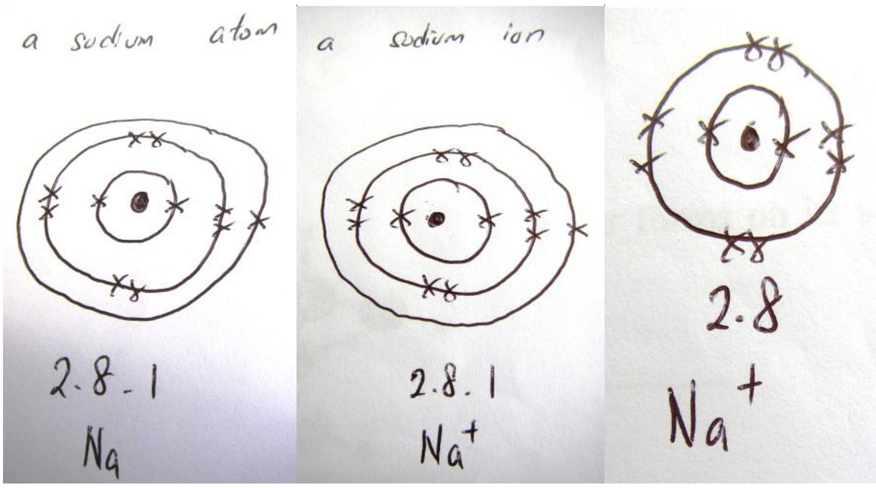


Figure 5.86: M2h

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
M3: [Taking a long time to draw] (see Figure 5.87)
I: So, the next part will be the sodium ion.
M3: [Drawing] (see Figure 5.87)
I: Can you describe the electron arrangement of the sodium atom and the sodium ion that you have drawn?
M3: [Participant did not seem to know what to do]
I: [Pointing at what the respondent has written down on his paper, i.e. 2.8.1]. Do you know the meaning of electron arrangement?
M3: [Reading: 2.8.1]
I: Ok. What is the electron arrangement of the sodium ion?
M3: 2.8
I: So, what do you think is the difference between a sodium atom and a sodium ion?
M3: [No response]

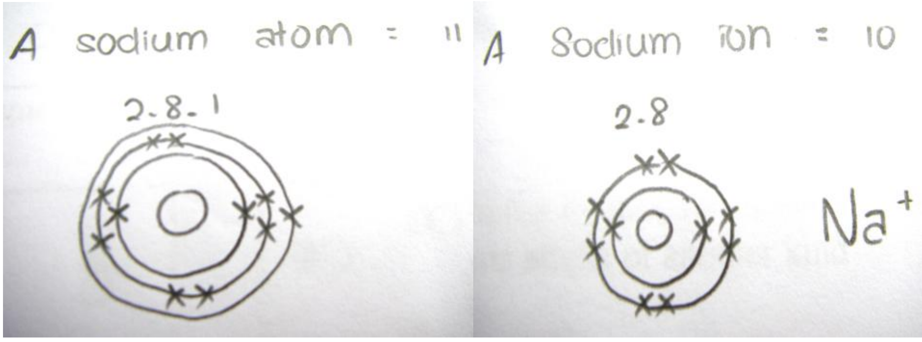


Figure 5.87: M3i

The High group

All the participants in this group could draw the electron arrangement of a sodium atom and a sodium ion within a short time, and can describe the electron arrangement correctly in drawing as well as in explanation (see Figures 5.88, 5.89, 5.90, and excerpts from the interview transcripts). Only H3 did not show the charge of the sodium ion. However, all of them could tell the difference between a sodium atom and a sodium ion, and can classify them according to the type of particle of matter.

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
H1: [Completed the drawing within a short time]. See Figure 5.88.
I: Can you describe the electron arrangement of a sodium atom and a sodium ion?
H1: [Writing down 2.8.1 for sodium atom and 2.8 for sodium ion].
I: What do you think is the difference between a sodium atom and a sodium ion?
H1: Sodium ion has a charge of 1+. It has 1 electron less than sodium atom.
I: How would you classify them according to the type of particle?
H1: Sodium atom is an atom while sodium ion is an ion.

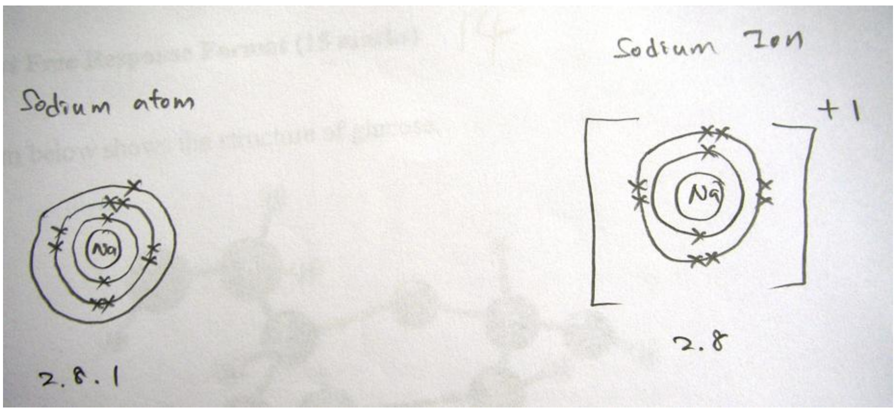


Figure 5.88: H1i

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
H2: [Drawing and labelling within a short time]. See Figure 5.89.
I: How would you describe the electron arrangement of a sodium atom and a sodium ion?
H2: The electron arrangement of sodium atom is 2.8.1. The electron arrangement of sodium ion is 2.8.
I: So what do you think is the difference between a sodium atom and a sodium ion?
H2: Sodium ion has achieved stable octet electron arrangement by donating 1e and it is a cation.
I: So the type of particle is different?
H2: Yes.

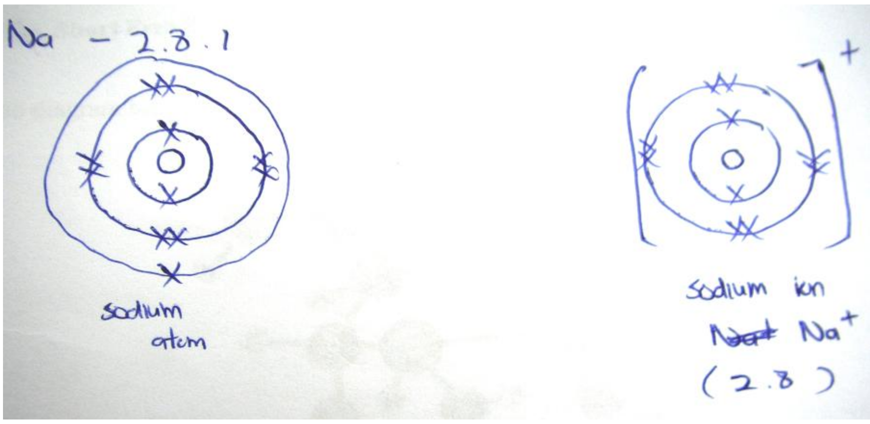


Figure 5.89: H2j

I: Can you draw the electron arrangement of a sodium atom and a sodium ion?
H3: [Drawing and labelling within a short time]. See Figure 5.90.
I: Ok. If I ask you to describe the electron arrangement of a sodium atom, what would you say?
H3: Sodium atom has electron arrangement of 2.8.1. The 11 electrons are arranged in 3 different shells.
I: So what do you think is the difference between a sodium atom and a sodium ion?
H3: Sodium atom has 1 electron more than sodium ion. Sodium ion has a charge of 1+.
I: So the type of particle is different?
H3: Yes.

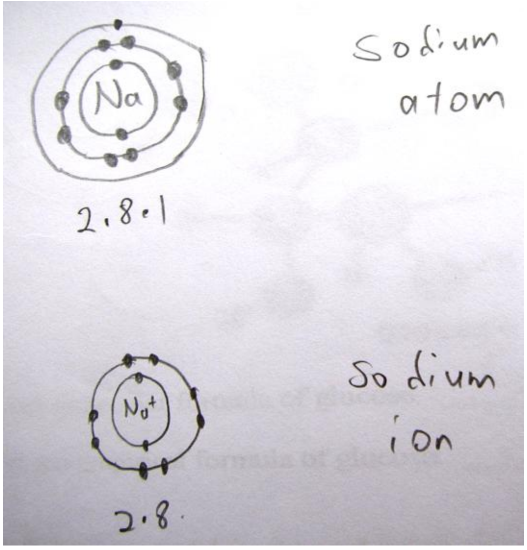


Figure 5.90: H3j

5.5.2.3 Multiple levels of representation

Question 1 of Worksheet 2 (*Appendix 26*) was designed to identify participant's levels of description. That is: whether the participant describes at the macroscopic, submicroscopic, or symbolic level, or a combination of these levels (multiple levels of representation). None of the nine participants was capable of using multiple levels of representation. Even participants from the High group tend to describe at the macroscopic level. Participants from the Medium group show most confusion between the three levels of description.

<u>The Low group</u>

The description of all the three participants was at the symbolic level only. Their interpretation of chemical equation was of a qualitative aspect only.

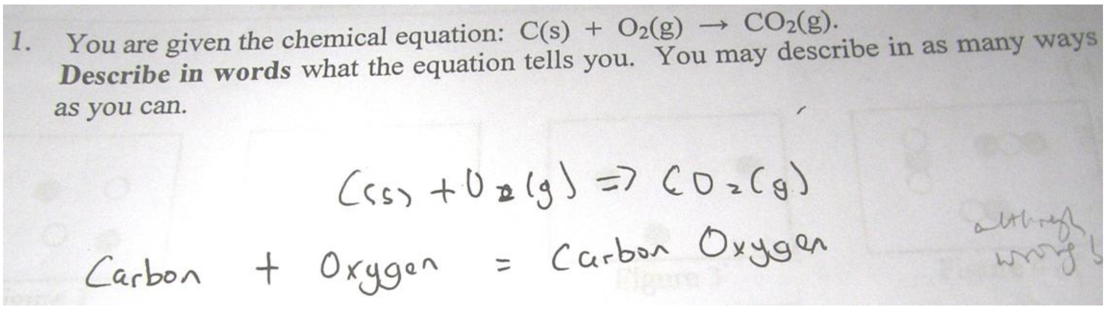


Figure 5.91: L1j

L1 just copied the chemical equation given and rewrote the same equation in words (symbolic), but the name `carbon dioxide' was wrongly written as `carbon oxygen' (Figure 5.91).

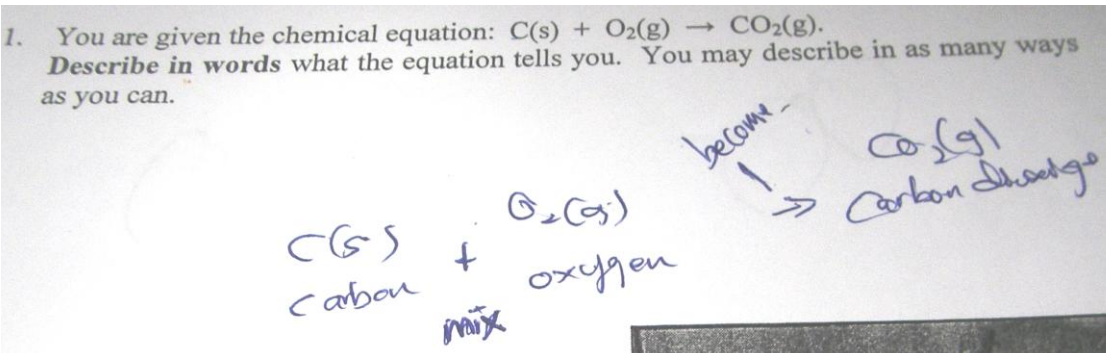


Figure 5.92: L2k

L2 also copied the chemical equation given in the question. He wrote the word equation (symbolic) correctly, but wrongly interpreted the process sign `+' as `mix' (Figure 5.92).

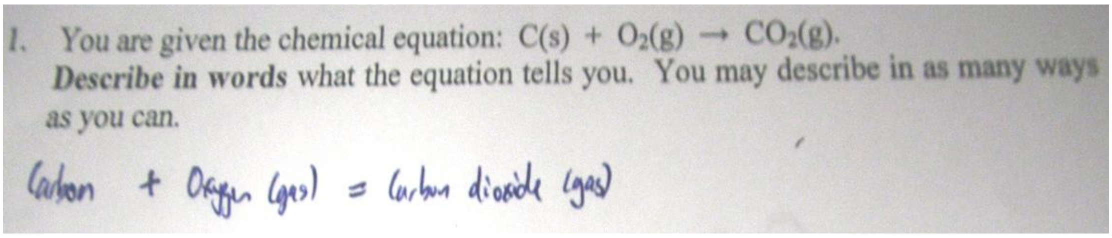


Figure 5.93: L3k

L3 merely translate the chemical equation given into a word equation (symbolic). No other description was given (Figure 5.93).

The Medium group

All the three participants only made qualitative interpretation of the chemical equation. They could neither distinguish nor relate the three levels of representation and hence, showed a confusing mixture of macroscopic, submicroscopic, and symbolic representations in their descriptions.

Submicroscopic level attempted by M1, with some wrong terms or concepts such as `atom' of carbon dioxide. M1 also could not represent by a many-particle system (Figure 5.94).

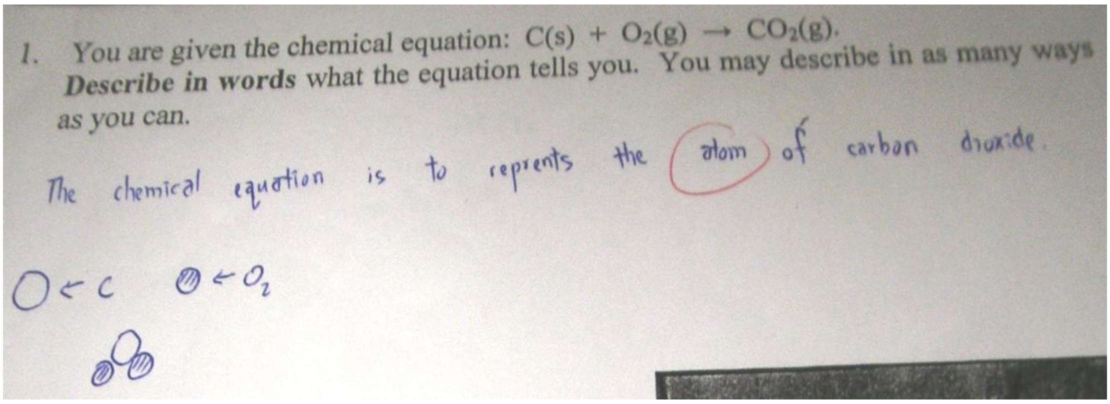


Figure 5.94: M1l

M2's description showed a mixture of submicroscopic term such as carbon atom and macroscopic term such as oxygen gas, and carbon dioxide (Figure 5.95). Instead of translating between the two levels, he seemed confused between the two levels, as he could neither translate nor relate between the two levels.

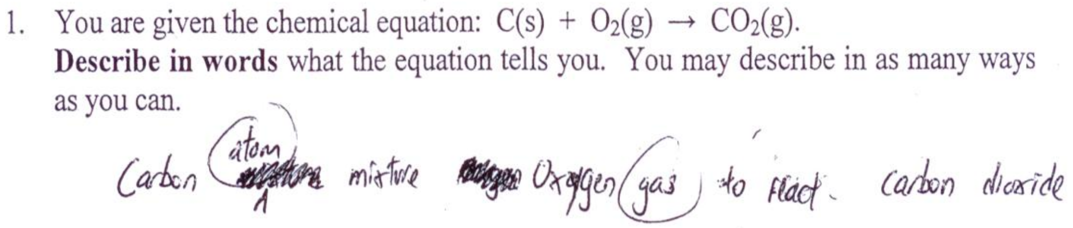


Figure 5.95: M2i

M3's description was at the macroscopic level only. He also had wrong conception of the process sign "+" which he interpreted as "mix up" (Figure 5.96).

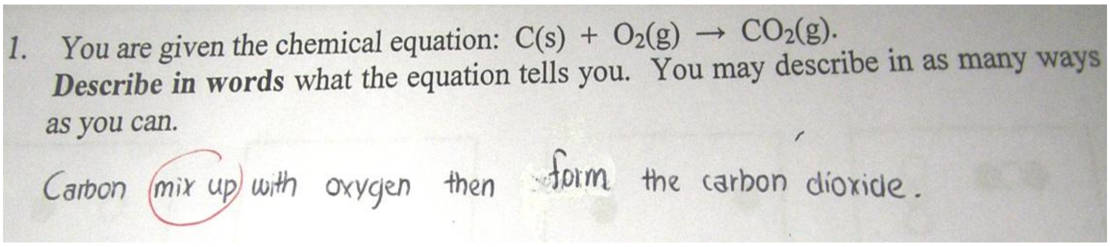


Figure 5.96: M3j

The High group

All the three participants gave a qualitative as well as quantitative interpretation of the chemical equation. However, all their descriptions were at the macroscopic level only. For example: carbon, solid carbon, 1 mol of carbon. None attempted at the molecular or submicroscopic level. For example: 1 atom or N_A atoms of carbon or 1 molecule or N_A molecules of oxygen. See Figures 5.97, 5.98 and 5.99. None of the participant realised the mole concept has both a macroscopic and a microscopic interpretation or perspective.

1. You are given the chemical equation: $C(s) + O_2(g) \rightarrow CO_2(g)$.
Describe in words what the equation tells you. You may describe in as many ways as you can.

Carbon reacts with oxygen gas to produce carbon dioxide.
1 mole of carbon reacts with 1 mole of oxygen gas to produce 1 mole of carbon dioxide
Solid carbon reacts with gaseous oxygen to produce carbon dioxide gas

Figure 5.97: H1j

1. You are given the chemical equation: $C(s) + O_2(g) \rightarrow CO_2(g)$.
Describe in words what the equation tells you. You may describe in as many ways as you can.

- carbon react with oxygen gas to produce carbon dioxide.
- The carbon and oxygen gas are reactant while carbon dioxide is the product.
- 1 mole of carbon react with 1 mole of oxygen gas to form 1 mole of carbon dioxide.
- The reaction is an oxidation of carbon.
- The product form is in gaseous state while the carbon is in solid state and the oxygen is in gaseous state.
- The product form is a covalent bond substance. [redacted]

Figure 5.98: H2k

1. You are given the chemical equation: $C(s) + O_2(g) \rightarrow CO_2(g)$.
Describe in words what the equation tells you. You may describe in as many ways as you can.

- Carbon reacts with oxygen gas to for carbon dioxide.
- carbon and oxygen gas are the reactants while carbon dioxide is the product.
- One mole of carbon reacts with one mole of oxygen gas to form one mole of carbon dioxide gas
- carbon is in solid state while oxygen and carbon dioxide are in gaseous state.
- Carbon undergoes oxidation because it gains oxygen and has an increase in oxidation number. [redacted]
- products formed only contain covalent bond.

Figure 5.99: H3k

Question 2 of Worksheet 2 (*Appendix 26*) was designed to identify participant's level of representational competence as suggested by Kozma and Russell (2005). Kozma and Russell (2005) provided a detailed picture of how representational competence can be assessed. The conceptual structure moves from the use of surface features to define phenomena, which is characteristic of novices within a domain, to the rhetorical use of representations, which is characteristic of expert behaviour. See Chapter 2: Literature Review (Section 2.4.5). For this study, a test item (Question 2) was presented. In addition, a video clip showing the reaction between sodium and chlorine was played twice to the participants during the interview. Students were then required to draw and explain how sodium reacts with chlorine to form sodium chloride. However, in this study, the five representational competence levels suggested by Kozma and Russell (2005) as scoring rubics were reduced to only four representational competence levels, as summarised in Table 5.23. Level 5 is irrelevant to this study as the theoretical perspective in this study is cognitive, with information processing theory as the main theoretical framework. Further more, the semi-structure interviews conducted in this study were individual interviews and not focused group interviews. No part of this study was done in a laboratory environment and no investigative task was involved. Assessments only engage participants in the use of representations to describe and explain chemical phenomena. They are paper-and-pencil assessments not used in a social context. The impact of the environment on the representational competence of the participants was not examined. Hence, the social context or situative perspective was irrelevant. Based on the scoring criteria in Table 5.23 as scoring rubics, the scoring of each participant's representational competence was worked through. Since representational competence focuses on the extent to which students are attuned to the use of formal chemical representations, only the overall quality of the participant's response was rated, rather than its "correctness", or the "chemical accuracy" of the representations.

Table 5.23
Scoring criteria of representational competence levels
(adapted and simplified from Kozma & Russell, 2005)

Level	Description
Level 1 Representation as Depiction	When asked to represent a physical phenomenon, the person generates representations of the phenomenon based only on its physical features. That is, the representation is an isomorphic, iconic depiction of the phenomenon.
Level 2 Early Symbolic Skills	When asked to represent a physical phenomenon, the person generates representations of the phenomenon based on its physical features but also includes some symbolic elements. The person may be familiar with a formal representational system but its use is merely a literal reading of a representation's surface features without regard to syntax and semantics.
Level 3 Syntactic Use of Formal Representations	When asked to represent a physical phenomenon, the person generates representations of the phenomenon based on both observed physical features and unobserved, underlying entities or processes, even though the represented entities or processes may not be scientifically accurate. The person is able to correctly use formal representations but focuses on the syntax of use, rather than the meaning of the representation. Similarly, the person makes connections across two different representations of the same phenomenon based only on syntactic rules or surface features, rather than the underlying meaning of the different representations and their features.
Level 4 Semantic Use of Formal Representations	When asked to represent a physical phenomenon, the person correctly uses a formal symbol system to represent underlying, non-observable entities and processes. The person is able to use a formal representational system based on both syntactic rules and meaning, relative to some physical phenomenon that it represents. The person is able to make connections across two different representations or transform one representation to another. The person can provide a common underlying meaning for several kinds of superficially different representations and transform any given representation into an equivalent representation in another form. The person spontaneously uses representations to explain a phenomenon.

Findings show participants from the Low and the Medium group tended to focus on depictions of physical observations at the macroscopic level. Only participants from the High group were able to use formal representations to stand for underlying, unobservable phenomena. Of the nine participants, three were scored at

Level 1, three at Level 2, another two at Level 3, and only one at Level 4. Considering the fact that it is a text book question, the response is unsatisfactory. In order to answer well, participants were expected to know basic chemical concepts such as fundamental particles of matter, that both sodium and chlorine are element, type of particles in sodium and in chlorine, physical state of sodium and chlorine at room condition and other related concepts.

Although the Form 4 Chemistry text book (pages 83 and 85, see *Appendix 26a*) shows representations of the reaction at all the three levels, the participants were more familiar with diagrams showing the laboratory set-up of the experiment (macroscopic) and symbolic representations, such as chemical equation of the reaction and symbolic representations of the particles involved in the reaction. Submicroscocpic representations showing the unobservable, underlying entities such as sodium atoms, chlorine molecules and sodium chloride as ions were not generated by any of the participants. This is not surprising as examination questions often focus on the symbolic level and hence teaching-and-learning as well. Although in recent years there has been a shift in focus towards including submicroscopic representations in SPM Chemistry examinations (beginning 2006), it appears this aspect of chemistry continues to be neglected in many chemistry classrooms.

<u>The Low group</u>

Generally, they are limited in their ability to use representations to explain physical phenomena. They tend to use representations as isomorphic, iconic depiction of a phenomenon. Participants in this group scored a representational competence level of either “Level 1” or “Level 2”.

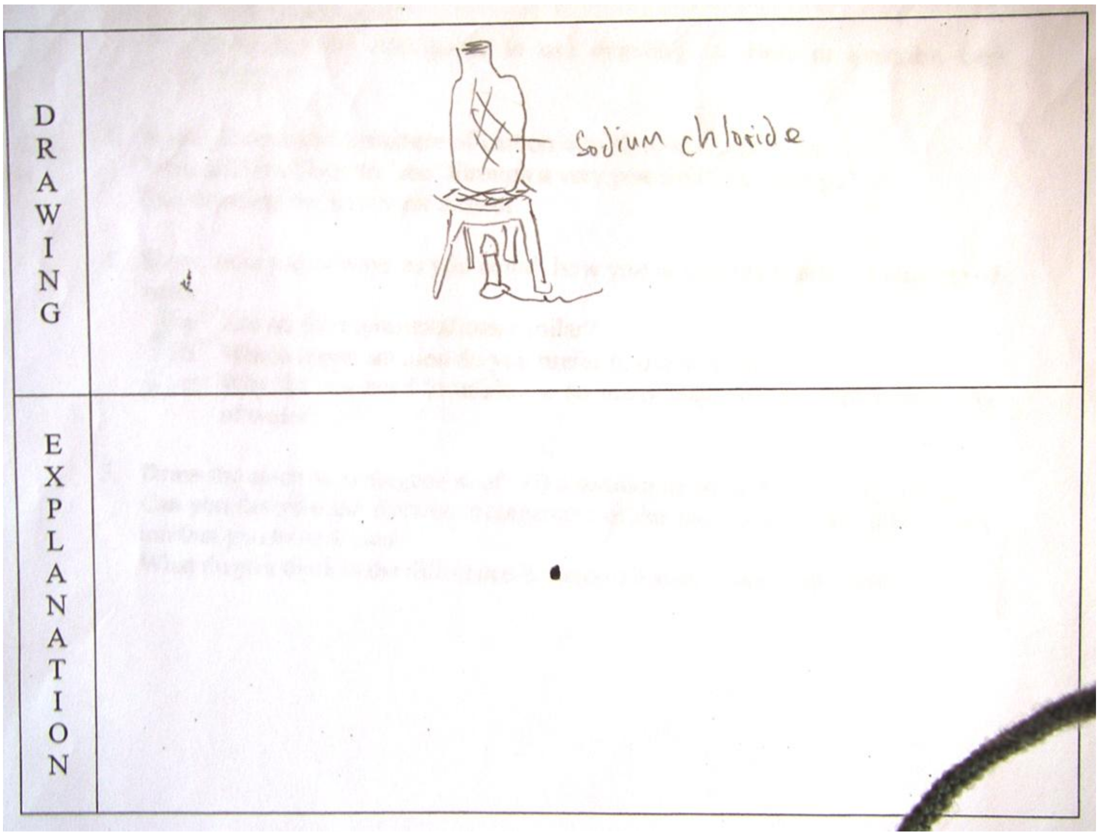


Figure 5.100: L1k

L1 merely provided a macroscopic level drawing showing the set-up of the apparatus (which was in fact incorrect), and named or labelled the product of the reaction (Figure 5.100). No explanation on how sodium and chlorine reacts to form sodium chloride was given. L1's response shows he has a macroscopic view of the reaction and provided evidence that he is operating at a "surface level" representational competence. Since L1 uses representations as depiction, the score for his response is at "Level 1".

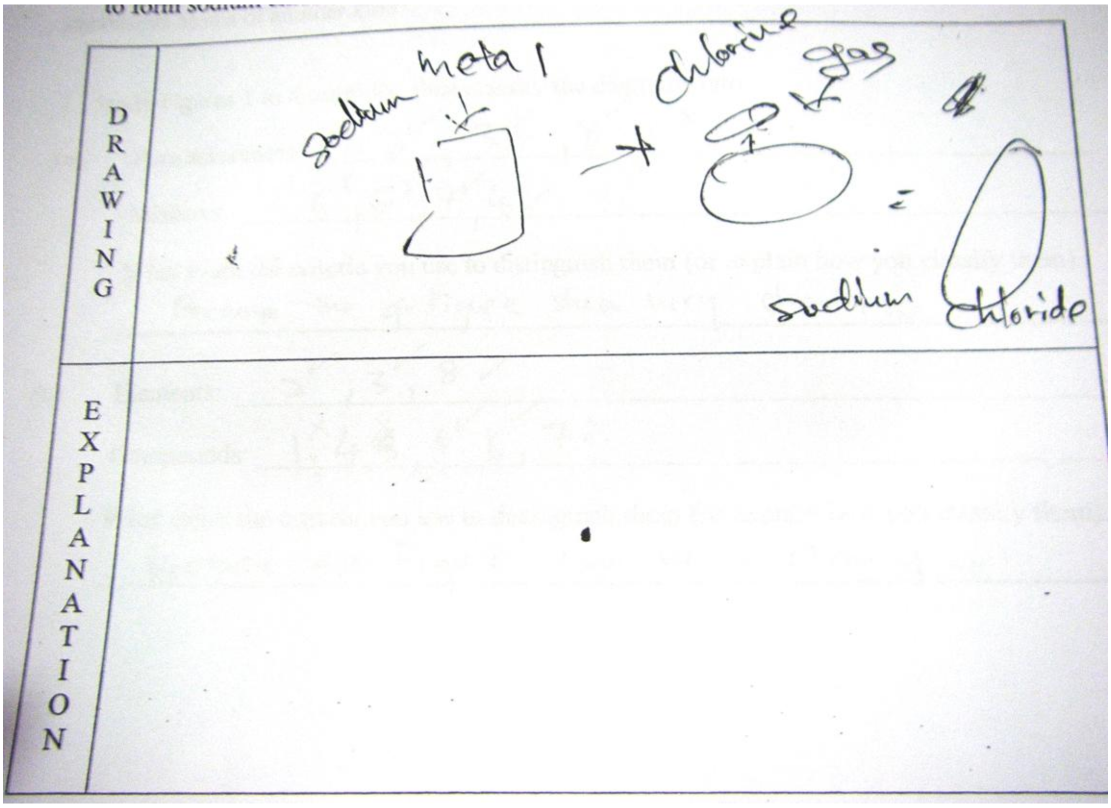


Figure 5.101: L2l

L2 appears to have a macroscopic view of the reaction only. He provided a macroscopic level drawing showing a piece of sodium metal, a container (that looks like a gas jar) of chlorine gas, and another figure which he labelled as sodium chloride (Figure 5.101). However, by including some symbolic elements such as the plus sign, "+", and the equal sign, "=", he seems to have generated a word equation to represent the reaction. Although the process sign "+" and the "=" sign could be interpreted to mean "react' and "yield', L2 failed to explain at the submicroscopic level, how sodium and chlorine react to form sodium chloride. His use of the representations may be without regard to syntax and semantics. Since L2 has acquired some early symbolic skills, the score for his response is at "Level 2".

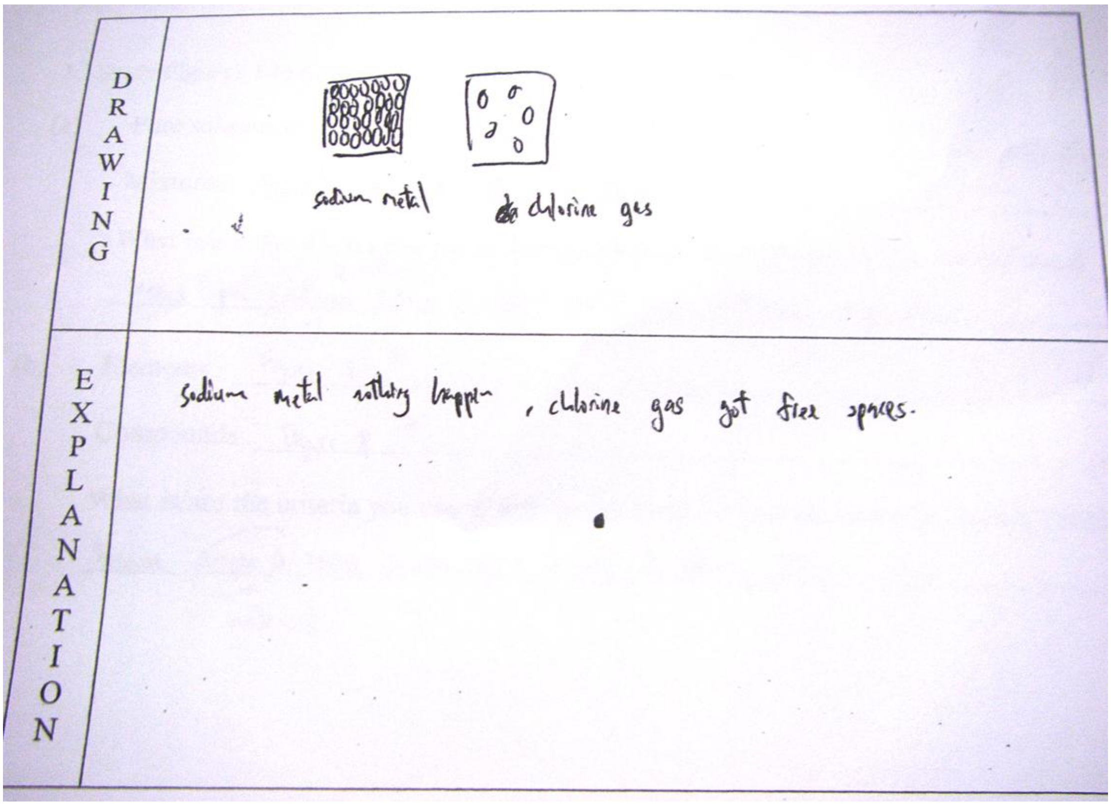


Figure 5.102: L3l

At the macroscopic level, L3 wrote the words “sodium metal” and “chlorine gas”, supposedly the reactants. He also generated two submicroscopic representations of the two reactants. The many small circles which are closely arranged could be taken to represent atoms within a solid, that is: sodium atoms in sodium metal. The few small circles which are far apart could be particles of chlorine gas, although L3 was unaware chlorine gas exists as diatomic molecules, Cl_2. However, L3 did not show how the product sodium chloride could be represented (Figure 5.102). Although submicroscopic representations were used to represent the unobservable, invisible entities (the particles), no description of the underlying process was provided. This provides evidence that L3 could not use these representations to explain how sodium and chlorine react to form sodium chloride. Instead, he was merely depicting what may be seen. Since L3 uses representations as depiction, the score for his response is at “Level 1”.

The Medium group

Participants from this group show a representational competence level of either “Level 1” or “Level 2”.

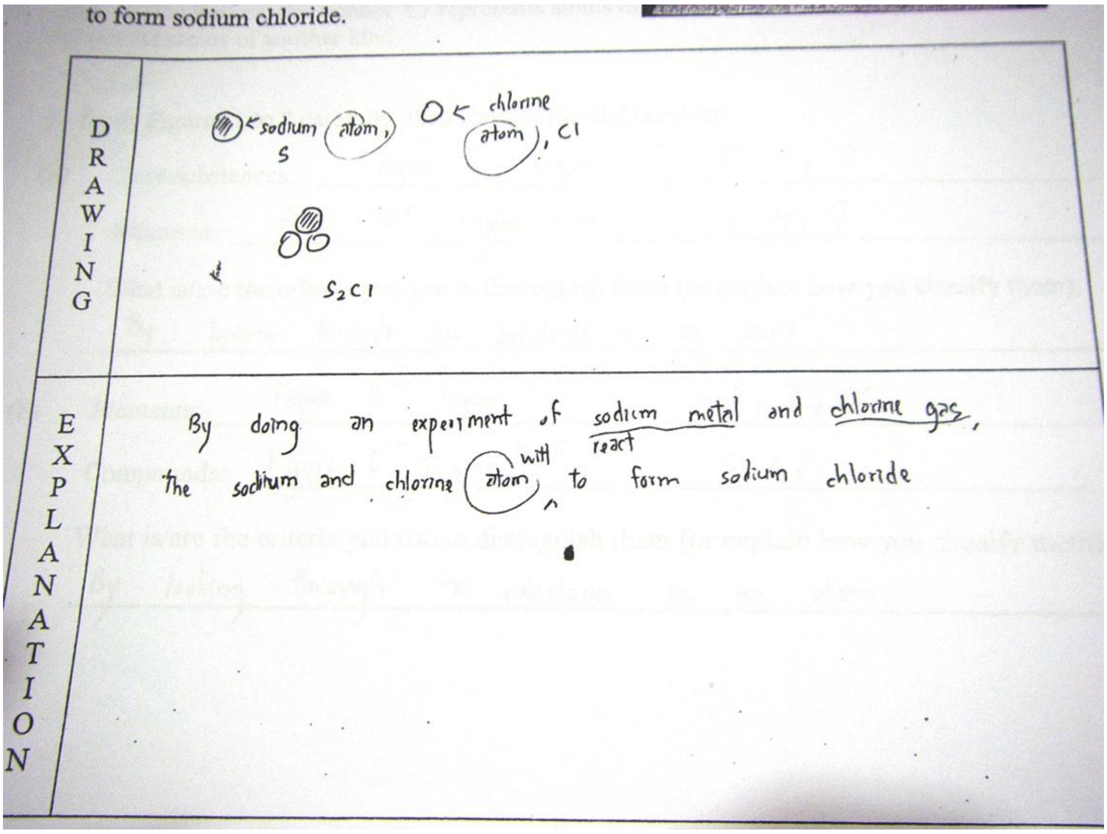


Figure 5.103: M1m

M1 merely drew and labelled a sodium atom, a chlorine atom, and another group of particle(s) scattered below. There doesn’t seem to be any connection between the particles as no process symbols were shown. Wrong chemical symbol for the element sodium was used (sodium atom was labelled as `S’). Chemical formula for sodium chloride was wrongly written as S_2Cl and the type of particle in sodium chloride was wrongly identified as molecule (Figure 5.103). Explanation focuses on macroscopic features and contains a mixture of macroscopic (such as sodium metal, chlorine gas) and submicroscopic (such as chlorine atom) terms. Since M1 uses representation as an iconic depiction, the score for his response is at “Level 1”.

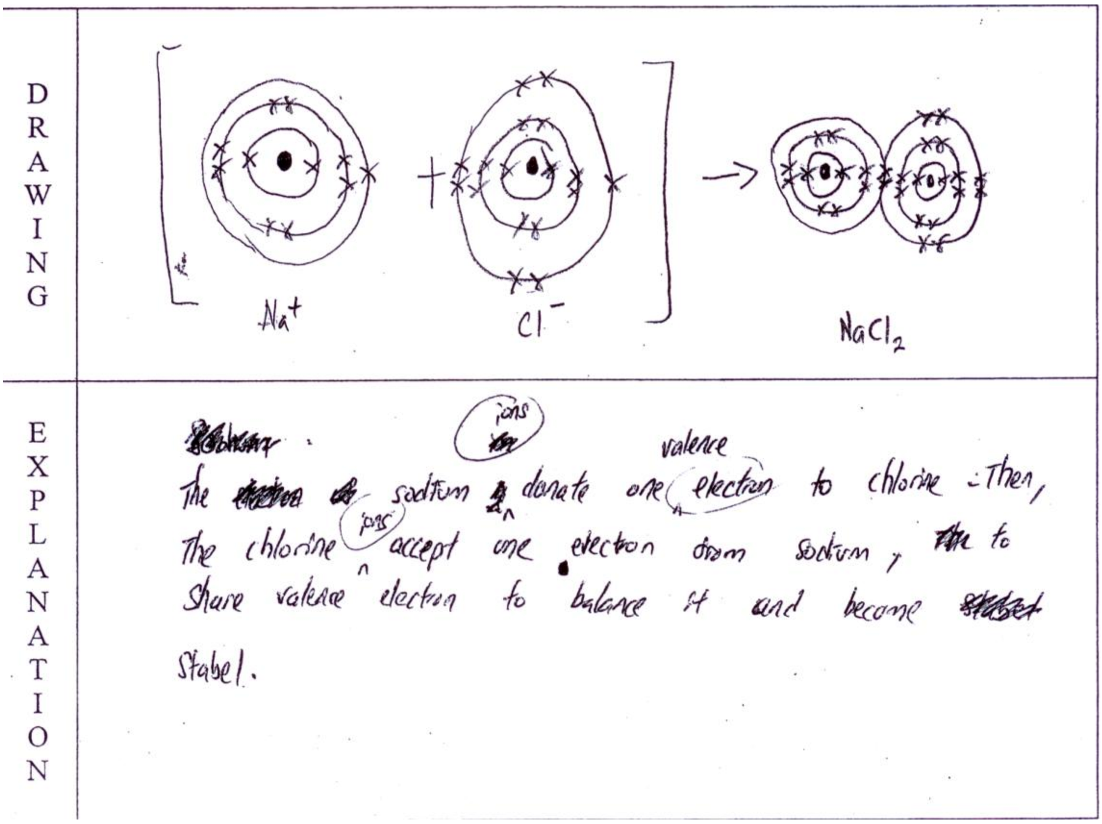


Figure 5.104: M2j

M2 attempted to generate representations of sodium atom and chlorine atom, and showed the ions in sodium chloride. However, the labels `Na^+, Cl^-, did not match correctly with the representations. Besides, the chemical formula for sodium chloride was wrong written as $NaCl_2$ and the type of particle in sodium chloride was wrongly represented as a covalent molecule. M2 included some symbolic elements such as process symbols "+" and "→", supposedly to show sodium and chlorine react to form sodium chloride. However, the explanation was messy and incorrect. This is evident that M2 has no idea about the unobserved, invisible entities and could not explain the underlying process taking place. Although M2 has acquired some symbolic skills, he merely uses the representations literally, without regard to syntax and semantics. The score for his response is at "level 2".

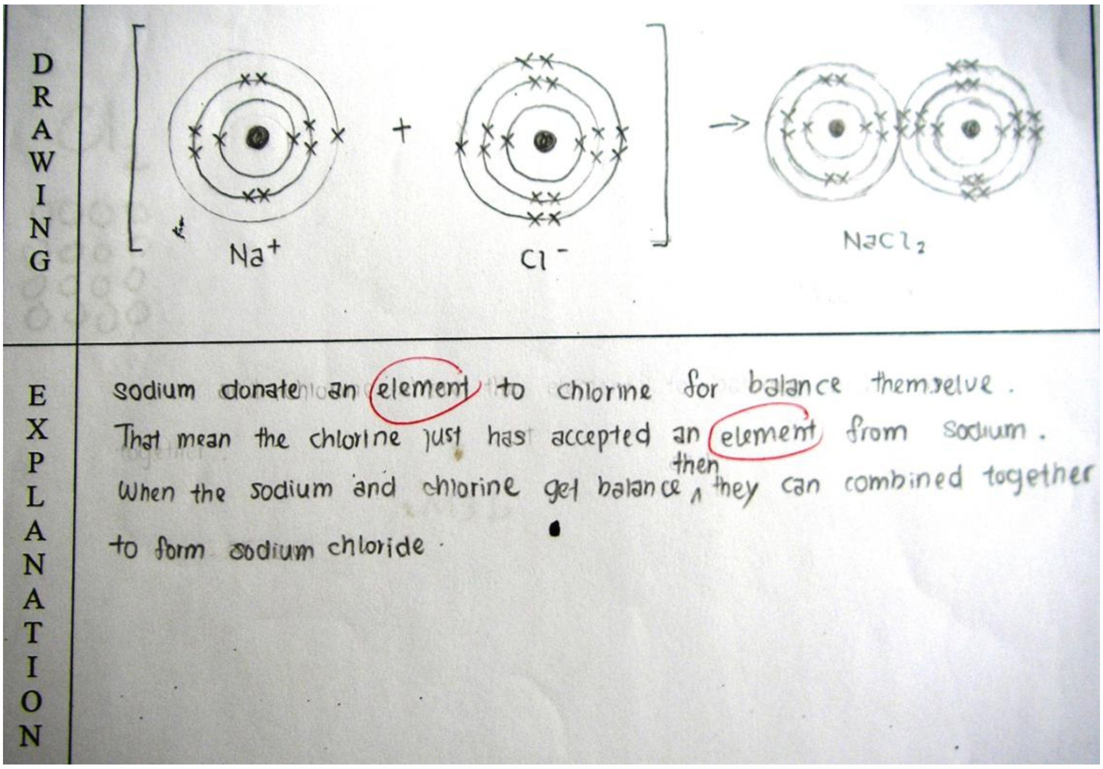


Figure 5.105: M3k

M3 also provided representations of submicroscopic entities and included some symbolic elements in his drawing. However, while the representations show sodium atom and chlorine atom, the corresponding labels shows Na^+ ion and Cl^- ion. Sodium chloride was wrongly represented as a covalent molecule and wrong chemical formula was given. Explanation was at the macroscopic level. Confusion between the concepts of atom (submicroscopic) and element (macroscopic) continues to prevail for M3. On a whole, explanation given was irrelevant and did not touch on any unobserved, underlying entities or processes. This provides evidence that M3 merely uses the representations literally without regard to syntax and semantics. Hence, score for his response is at “level 2”.

<u>The High group</u>

A mix of observed physical features and unobserved, underlying entities or processes was represented. Only one participant (H2) from the High group could correctly use formal representations to represent the underlying, unobserved entities and processes. He was scored a representational competence level of “Level 4”. The other two participants were only scored at “Level 3”.

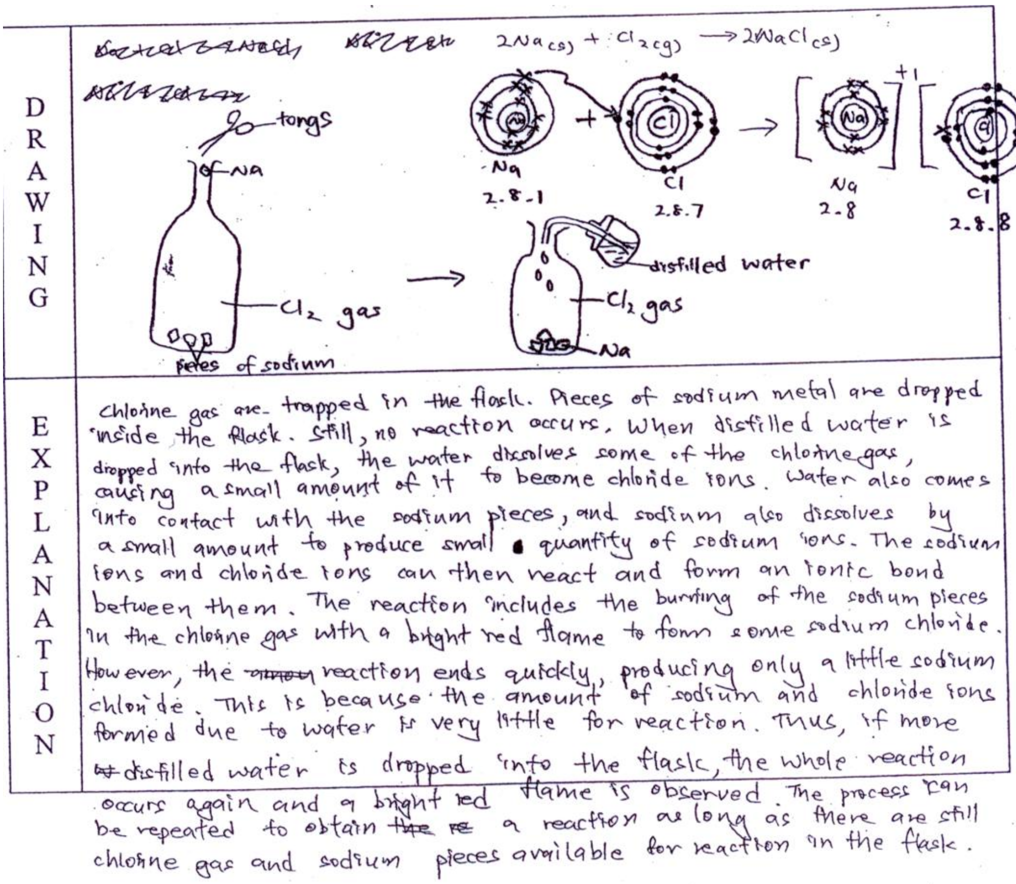


Figure 5.106: H1k

H1 provided a macroscopic level drawing showing the apparatus and materials for the reaction between sodium metal and chlorine gas. He also wrote a chemical equation (symbolic) to represent the reaction. Electron-dot representations (symbolic) were also generated to show how a sodium atom donates an electron to a chlorine atom to form Na^+ ion and Cl^- ion (Figure 5.106). H1 gave a lengthy explanation but the description focussed on the observable, macroscopic features of the phenomenon. He did not explain at the submicroscopic level how sodium and chlorine react to form sodium chloride. Although H1 generates representations of the phenomenon based on both observed physical features and unobserved, underlying entities and processes, makes connections across 2 different representations of the same phenomenon, correctly uses formal representations, he only focuses on the syntax of use, rather than the meaning of the representation. His response is scored at “level 3”.

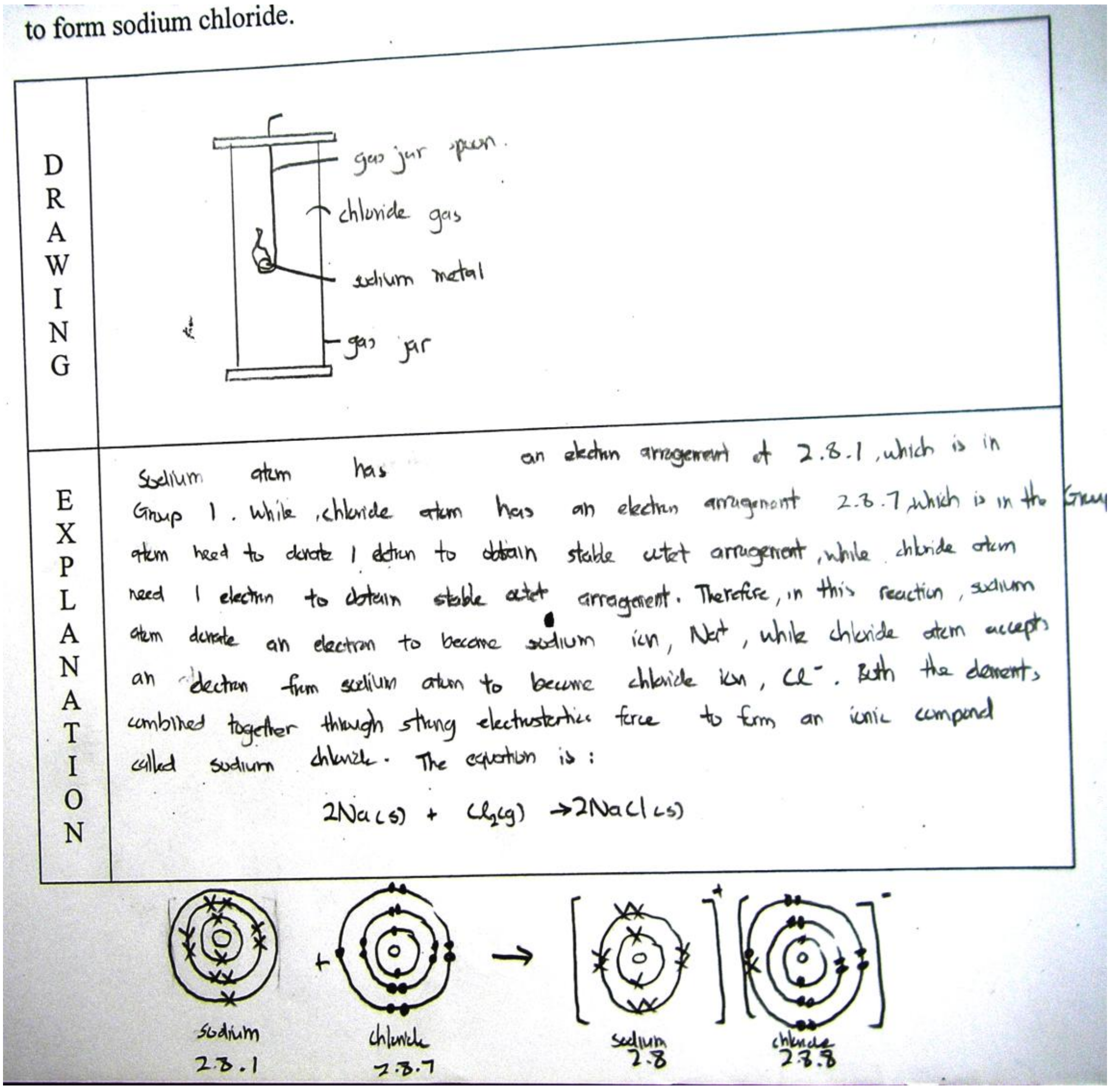


Figure 5.107: H2l

Apart from providing a macroscopic level drawing showing the reaction between sodium and chlorine, H2 wrote a chemical equation (symbolic) to represent the reaction between the elements sodium and chlorine to form the compound sodium chloride. He also explained, with the help of electron-dot representations, why and how electron transfer took place between sodium atom and chlorine atom to form sodium ion and chloride ion, and subsequently, formation of the ionic compound sodium chloride. Although in the diagram both sodium atom and sodium ion were merely labelled as sodium, and chlorine atom and chloride ion wrongly labelled as chloride, submicroscopic terms of atom and ion were included in the explanation. H2 correctly uses a formal symbol system to represent underlying, unobservable entities and processes, able to use a formal representational system based on both syntactic rules and meaning to describe the reaction between sodium and chlorine forming sodium chloride, able to make connections across different representations, can transform one representation to another and spontaneously uses representations to explain a phenomenon. The score for his response is at "Level 4".

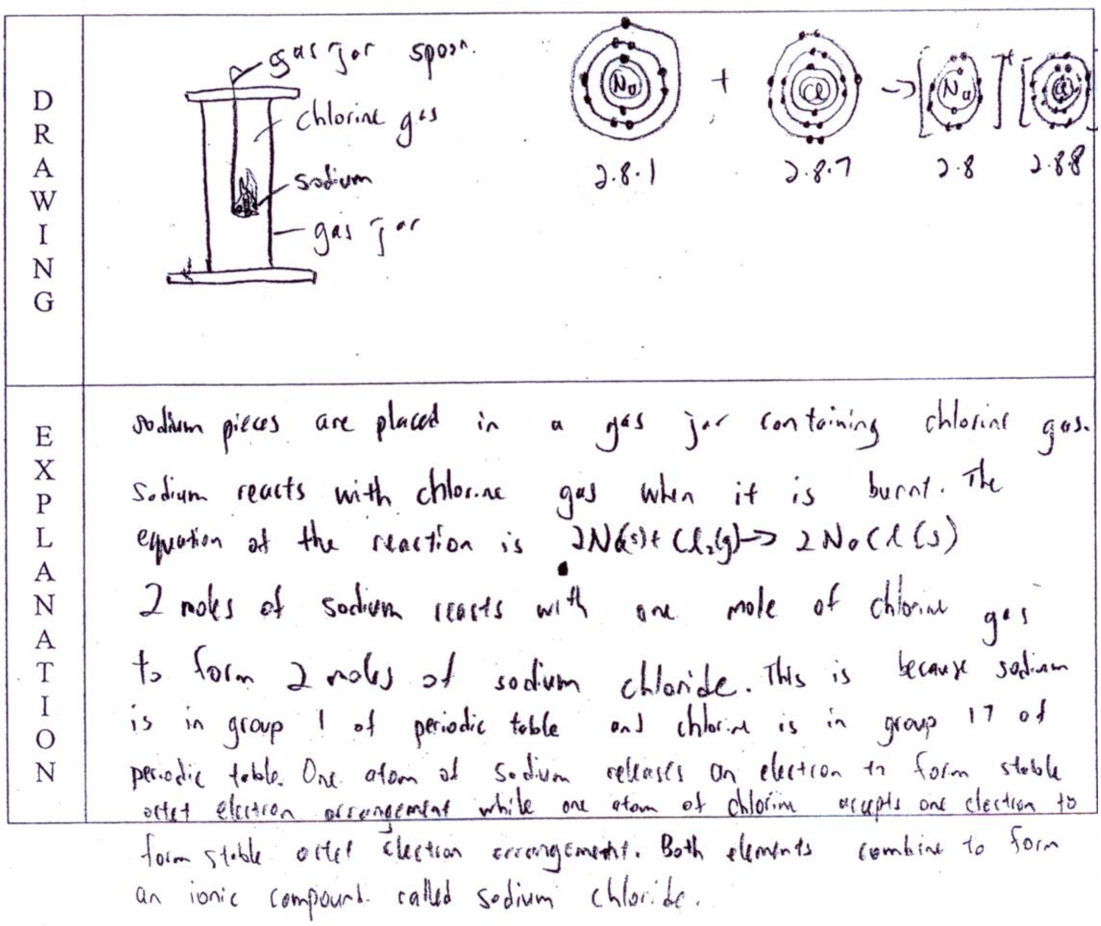


Figure 5.108: H3l

H3 also provided a macroscopic level drawing showing the reaction between sodium and chlorine, and wrote a chemical equation (symbolic) to represent the reaction between the elements sodium and chlorine to form the compound sodium chloride. However, he did not name or label the submicroscopic entities (sodium atom, chlorine atom, sodium ion, chloride ion) in the diagram. In the explanation, H3 only mentioned sodium atom and chlorine atoms but not the ions formed. Submicroscopic terms were used sparingly. Although H3 generates representations of the phenomenon based on both observed physical features, and unobserved, underlying entities or processes, able to correctly uses formal representations, he only focuses on the syntax of use, rather than the meaning of the representations. He was able to make connections across different representations of the same phenomenon but based only on syntactic rules or surface features, rather than the underlying meaning of the different representations and their features. The score for his response is at "Level 3".

As expected, no participant showed `reflective, rhetorical use of representations' (Level 5), since the assessment was not designed to test this level of representational competence. Table 5.24 summarises the representational competence level (Kozma & Russell, 2005) of the nine respondents from the Low, the Medium, and the High group.

Table 5.24
Representational competence levels of the interview participants

Respondent	Representational competence level
L1	Level 1: Representations as depiction
L2	Level 2: Early symbolic skills
L3	Level 1: Representations as depiction
M1	Level 1: Representations as depiction
M2	Level 2: Early symbolic skills
M3	Level 2: Early symbolic skills
H1	Level 3: Syntactic use of formal representations
H2	Level 4: Semantic use of formal representations
H3	Level 3: Syntactic use of formal representations

Note: L=Low; M=Medium; H=High

5.5.3 Section summary

All the nine participants in the interviews were unfamiliar with the term `chemical representations'. However, participants from the [1]High group gave correct examples of chemical representations while participants from the [2]Low group totally had no idea about chemical representations. Participants from the Low group held a macroscopic view of matter, focused on the surface features of representations and used representations as depictions. Their ability to interpret or generate representations of chemical concepts, and to translate between representations, is limited; participants from the [3]Medium group had a microscopic view of matter. Microscopic terms were used only when prompted, and chemical representations were sometimes incorrectly used; participants from the High group had both a macroscopic view and a microscopic view of matter, able to use microscopic terms appropriately and spontaneously, could generate submicroscopic representations using correct chemical representations, and able to translate fluently between representations. None of the nine participants was capable of using multiple levels of representations in their description. The representational competence levels of the nine participants were: three at level 1, three at level 2, two at level 3, and one at Level 4.

5.6 Chapter Summary

In this chapter, the findings for each research question have been summarised under the section summary in their respective sections (Section 5.1 to Section 5.5). A summary of all the findings in this study will also be given in Chapter 7. Hence, the main findings are not repeated in the chapter summary.

In the next chapter, the regression model that emerged from the findings will be discussed.

[1] subjects whose TRC scores were in the top 25%
[2] subjects whose TRC scores were in the bottom 25%
[3] subjects whose TRC scores were in the middle 50%