CHAPTER 7

SUMMARY, IMPLICATIONS, AND CONCLUSIONS

7.0 Introduction

This study was designed to investigate Form four science students' representational competence of basic chemical concepts. Specifically, the study attempted to assess students' overall levels of understanding of basic chemical concepts, chemical representations, as well as their representational competence in chemistry. It also sought to compare students' with different levels of understanding of chemical concepts and chemical representations in their representational competence. In addition, an attempt was made to identify their alternative conceptions of chemical concepts, chemical representations, as well as their difficulties when interpreting and using chemical representations. Semi-structured interviews were conducted to gain further insights into selected students' representations of basic chemical concepts. A further search was undertaken to explore possible relationships between students' prior knowledge, working memory capacity, developmental level, learning orientations and their representational competence in chemistry, and subsequently, to determine the best predictor variable for representational competence. A total of 411 Form four science students from seven urban secondary schools in Perak participated in this study. Data for the study was obtained from seven instruments namely: The Test on Chemical Concepts (TCC), the Test on Chemical Representations (TCR), the Test on Representational Competence (TRC), the Classroom Test of Scientific Reasoning (CTSR), the Digit Span Backwards Test (DSBT), the Learning Approach Questionnaire (LAQ), and semi-structured interviews (SSI). The Statistical Package for the Social Sciences (SPSS) was used to process and analyze quantitative data collected from the study.

This chapter gives a summary of the findings of the study. Implications from the findings are included. Further research is also suggested.

7.1 Summary of the Findings

A summary of the findings in this study shall be presented following the sequence in the research questions and inferences made accordingly.

7.1.1 Students' understanding of chemical concepts, chemical representations, and their representational competence

Means for TCCt, TCRt, and TRCt scores were respectively 13.68 (45.60%), 18.63 (51.75%), and 16.90 (42.25%). See Table 7.1.

Table 7.1
Mean, standard deviation, minimum and maximum of TCCt, TCRt, and TRCt Scores

Test scores	n	Mean (%)	SD	Minimum (%)	Maximum (%)
TCCt	383	13.68 (45.60)	3.904	5 (16.67)	25 (83.33)
TCRt	379	18.63 (51.75)	3.274	7 (19.44)	27 (75.00)
TRCt	384	16.90 (42.25)	7.781	1 (2.50)	40 (100.00)

7.1.2 Comparing subjects with different levels of understanding of chemical concepts and chemical representations in their representational competence

(i) One-way ANOVA, F (2, 358) = 90.10, $p < 0.001$, and subsequently the post hoc Scheffe tests revealed students with a high level of understanding of chemical concepts had significantly higher overall level of representational competence compared to both the medium and the low groups, at $p < 0.001$. However, students with medium and low levels of understanding of chemical concepts showed no significant difference in their overall levels of representational competence, at $p < 0.001$.

(ii) One-way ANOVA, F (2, 349) = 16.94, $p < 0.001$, and subsequently the post hoc Scheffe tests revealed 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 at $p < 0.001$, while those with medium and low levels of understanding of chemical representations showed no significant difference in their overall levels of representational competence, at $p < 0.001$.

7.1.3 Students' alternative conceptions of basic chemical concepts and chemical representations

(i) Students' alternative conceptions of basic chemical concepts

The percentage of alternative conception for 18 of the 30 items in the TCC exceeded 50% (see Tables 5.11 and 5.14). Mean or percent mean alternative conceptions for 9 of the 12 categories of basic chemical concepts exceeded 50%. The mean or percent mean alternative conceptions for the first 5 categories of the most basic chemical concepts also exceeded 50% (see Table 5.12). It could be inferred that alternative conceptions of the most basic chemical concepts are very common among Form four science students.

(ii) Students' alternative conceptions of chemical representations

The percentage of alternative conceptions for 13 of the 36 items in the TCR exceeded 50%. `The three levels of representation of matter' is the content domain with the highest percent mean alternative conception (71.93%) while the content domain with the lowest percent mean alternative conception is `models' (36.71%).

This suggests 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 (see Table 5.16).

7.1.4 Students' difficulties in interpreting and using chemical representations

Percent difficulty for 23 of the 40 items in the TRC exceeded 50%. The category with the highest percent mean difficulty (78.83%) is RC3 - the ability to translate between different representations across levels while the category with the lowest percent mean difficulty (31.97%) is RC2 - the ability to translate between different representations at the same level. Comparing the percent mean difficulty, it could be inferred that the subjects of this study encountered most difficulty translating between different representations across levels and least difficulty translating between different representations at the same level (see Table 5.20).

7.1.5 A comparison of form students of High, Medium, and Low levels of representational competence in their representations of basic chemical concepts

(i) Students' conceptions of chemical representations

All the nine participants were unfamiliar with the term "chemical representations". However, participants from the High group gave 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 about chemical representations.

Generally, students tend to perceive particles as mini-versions of the substances they compose. These problems indicated limited understanding of the macroscopic, microscopic, and the symbolic levels, as well as confusion between the three levels of representations of matter.

The symbol `Cu' is most commonly interpreted as representing 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.

All the nine participants had seen the symbols O_2, 2O and O^{2-}, knew the number `2' in each of these symbol has different meaning but only participants in the High group could explain the meaning, and could easily distinguish between `atom', `molecule', and `ion'.

Participants in the Low group did not know what a ball-and-stick model represents and could not distinguish model from reality. Participants in the High group knew ball-and-stick models of common molecules very well. Participants in the Medium group had the most confusion.

All the participants knew the two symbols Cl_2 and $Cl_2(g)$ are different but only one of them could explain the difference. Generally, they had no idea what a one-particle system and a many-particle system is.

On submicroscopic representations, scores for the Low group in the Online Quiz ranged from 28% to 100%. Participants in the Medium group obtained the same score (57%) while participants in the High group obtained 100%. For Worksheet (1), participants in the High group chose the correct options and could explain the criteria of classification. Participants in the Low and the Medium groups could not explain the criteria. It could be inferred that participants in the High group had sound understanding of basic chemical concepts and were very familiar with submicroscopic representations of these concepts.

(ii) Students' representational competence

On the TRC (see Appendix 15a), eight of the nine participants either scored both items (A19 and A22) correctly or incorrectly. Participants in the Low and the Medium groups chose the wrong option. Participants in the High group chose the correct option and could explain their choice of option. It could be inferred that the High group had no difficulty translating submicroscopic representation to symbolic representation such as a chemical equation. For item B3, participants in the High group could distinguish between an atom and an element and could represent the concepts correctly. Participants in the Low group could not represent the chemical concepts while participants in the Medium group were confused between these two concepts.

On student generated representations, only one drawing from the Low group represented the water molecules correctly. The medium group showed the correct chemical representation of the water molecules. Submicroscopic representations of water were generated by the High group using the correct chemical representation of the water molecule.

Participants in the Low group held a macroscopic view of matter and tended to focus on the surface features of a substance. Participants in the Medium group had a microscopic view of matter. The type of particle for a pure element is correctly identified but they were not aware of the arrangement of particles in a solid like copper. The High group had both a macroscopic and a microscopic view of matter. The type of particle, as well as the arrangement, was correctly depicted.

Participants in the High group used the correct chemical representations to depict the oxygen and the carbon dioxide molecules. Arrangement of particles shown is appropriate for a mixture of gases. Microscopic terms such as `molecules' were used. For participants in the Medium group, the chemical representations used were inappropriate. Microscopic terms such as molecules are missing in the diagram and in their explanation. Participants in the Low group represented the molecules incorrectly.

A total of seven different correct representations of the water molecule were generated. The space-filled model appears to be the most common representation of the water molecule among the participants.

Generally, 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 Medium group had a microscopic view of matter. However, 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 participant in the semi-structured interviews was capable of using multiple levels of representation in their description. 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 (see Table 5.23).

7.1.6 Correlations between selected cognitive variables and representational competence

While there were strong positive correlations ($r=0.745$, $p<0.001$) between TCC score and TRC score, CTSR score and TRC score ($r=0.731$, $p<0.001$), moderate positive correlation between TCR score and TRC score (0.365, $p<0.001$), there was only a weak positive correlation ($r=0.178$, $p<0.01$) between LAQ score and TRC score. The relationship between DSBT score and TRC score ($r=0.036$) was very weak and statistically not significant (see Table 6.2: Correlation matrix).

7.1.7 The regression model

The regression equation derived in this study in the form $Y = b_0 + b_1X_1 + b_2 X_2+b_3 X_3$, that is: $Y = -9.731 + 0.933X_1 + 0.777X_2 + 0.421X_3$, can be used to predict the representational competence (Y) of a student if values for X_1, X_2, and X_3 were available. The best predictor variable of representational competence is understanding of chemical concepts (X_1) or prior knowledge I. The regression model with three independent variables explains more than 71% of the variance of representational competence (see Chapter 6 - Table 6.17). Prior knowledge (understanding of chemical concepts and understanding of chemical representations) accounts for approximately 58% of the variance, while developmental level accounts for the remaining 14%. The regression model was a good fit (Adjusted R^2 = 71%). The overall relationship was significant, [F (3, 188) = 156.405, $p< 0.001$].

7.2 Implications of the Study

As discussed in Chapter 1 and Chapter 2, Chemistry is a difficult subject to teach and to learn. This is described clearly by Bucat (2002a) as follows:

> "Chemistry is a complex and ill-defined field that requires considerable skill and effort to teach and to learn, and requires the joint efforts of chemistry education specialists and content specialist in all fields working together to analyze the demands of learning chemistry to find better ways forward."

Several implications to the teaching and learning of chemistry in Malaysian classrooms, as well as chemical education in Malaysian secondary schools in general can be drawn from the findings of this study. These implications for practice pertaining to instruction, curriculum and assessment are now discussed.

Implication 1: Use research to inform practice

Many of the alternative conceptions identified in this study are present in other educational contexts (Franco, 2005) and also diagnosed among more advanced chemistry learners (Stains & Talanquer, 2007). As alternative conceptions are resistant to change once they are strongly attached to learners' conceptual network in the LTM, identifying and addressing specific alternative conceptions of novice chemistry learners is crucial. Hence, teachers should be exposed to research. Semi-structured interviews conducted in this study also revealed majority of the participants did not actively mention any information unless they were prompted by the interviewer. Indeed, a lot of probing is needed to facilitate learning among the average learners while scaffolding is seen as crucial to help the weak learners. Hence, awareness and knowledge of research findings would be useful when making decision about teaching strategies, in particular teachers who handle novice learners. The heart of the teaching process is how teachers teach. On subject content, apart from possessing sound understanding of chemical concepts and principles, chemistry teachers should be well-informed of common alternative conceptions of these concepts and principles. On pedagogy, they should be aware that chemical concepts are often introduced to the students in a manner that are not consistent with their prior knowledge, constantly probe students' conceptions of each basic chemical concept to evaluate their understanding before introducing a new, related or more advanced chemical concept.

Implication 2: Emphasize the link between the three levels of representation of matter

Students do not always understand the role of the representation that is assumed by the teacher. Yet, students are usually expected to integrate the three levels of representations into a consistent whole. Teachers assume students can learn to navigate between the different types or levels of representations. Unfortunately, such expectation and assumption are often unfounded. Findings of this study show students encountered much difficulty understanding and finding the links between representations. Findings also indicate that developing this understanding and skill (representational competence) seem a challenging task for novice learners. Such findings strongly suggest the need for teaching approaches that pay more attention to helping students integrate their knowledge by emphasizing the relationships between the different representations and presenting them concurrently during instruction to help learners make the logical connections. Due to the abstract and content-based nature of chemical representations, explicit instruction is generally needed to help learners. The link between the macroscopic, microscopic and symbolic levels must be explicitly taught. Molecular representations must be linked to the corresponding macroscopic and symbolic representations. However, to ensure linkages are formed in the LTM, numerous opportunities should be given to learners to relate the three levels of representations.

Implication 3: Provide opportunity for student to generate their own representations

Student-generated representations from the participants of the semi-structured interviews in this study provided valuable insights. Hence, it is suggested that chemistry instruction provide opportunities for students to express their understanding in more than one way such as talking aloud, drawing or generating their own representations. For example, having students express their understanding of the molecular level in drawings accompanied by written or verbal explanation is a powerful way of helping students shift their focus from the macroscopic world to thinking about the invisible, molecular world. Students' drawings can also provide valuable information for teachers about how students interpret, relate and integrate representations depicting the macroscopic, symbolic and molecular levels of chemical concepts. Resorting to just paper-and-pencil tests rarely provides adequate information why students fail because we do not know how they develop their arguments. If we know how our students think and how they choose special options, we can help them and use the information to reinforce or alter particular aspects of our teaching. It is suggested that such particulate drawings be used for both instructional purposes as well as for formative assessment in class. On the usefulness of particulate drawings, Nakhleh (2002) commented:

> …such drawings are useful tools for teachers to assess their students' understanding of molecular level concepts. It can also reveal a great deal about what the students know and do not know about the molecular nature of chemistry. Even incomplete or incorrect drawings are also a very powerful teaching moment as these enable us to see what further explanations are needed (Nakhleh, 2002, p.3).

Implication 4: Elicit students' ideas instead of asking for correct answers

Teachers should not make the assumption that weak learners know nothing. Findings from the semi-structured interviews conducted in this study showed that all the three participants from the Low group could respond both verbally and in drawing, providing rich data source that is thought-provoking (see *Appendix 22a*- sample of interview transcript for the Low group). Excellent instruction from teachers alone is insufficient to ensure success. For effective learning, output from learners is equally important. However, teachers should recognise the difference between eliciting students' ideas and asking students for correct answers. It is suggested that rather than merely asking for the correct answer, teachers need to elicit students' ideas and then help them think about their ideas in relation to the ideas they are trying to understand. Use of `the right answer syndrome' allow students to get by with rote learning, making no effort to relate new concepts to prior knowledge (Wandersee, Mintzes, & Novak, 2000). Besides, use of `the right answer syndrome' mainly involves the good students while weak students are sidelined.

Implication 5: Responsibility of curriculum planners

As an elective subject, chemistry is only allocated a total learning time of four periods (or 140 minutes) a week at the Form four and Form five levels. However, findings of this study show students' overall level of understanding of basic chemical concepts is unsatisfactory. Hence, curriculum planners should also be informed of research findings. Perhaps the time allocation for chemistry could be increased to five periods a week to allow more time to teach basic chemical concepts which become the base for future chemical education. Teachers are the interface between the curriculum and the learners. If the practitioners (classroom teachers) face too much time constraint in carrying out their task, they might be unable to translate the intentions of the curriculum planners into fruitful learning.

Implication 6: Use the curriculum specifications carefully and creatively

Curriculum specification is merely a guideline to be used creatively, not to be followed rigidly. For example: concepts like pure substances and mixture, elements and compounds, atoms and molecules are included in the Form 4 Chemistry Curriculum Specifications (Malaysia, Curriculum development Centre, 2006a). As teaching often follows the order as is presented, students generally have little problem learning the above pairs of concepts. However, findings of this study show many students could not see the link between concepts like atom (a microscopic entity) and element (a macroscopic term). They either could not relate the two concepts or have problem distinguishing between the concepts when different combinations are used. Merely memorising definitions and examples will result in rote learning. More emphasis should be placed on helping students distinguish between concepts, see the link between concepts, and getting to know wrong examples is as important as learning correct examples.

Implication 7: Rethinking the old way - bringing back the chemistry text book

Text books are often regarded as a traditional learning resource. However, findings of this study indicate a need for text books to be used more frequently. Hence, the present study suggests bringing back the text books into the chemistry classroom. The Form Four Chemistry text book (Tan, 2005) is a good teaching and learning resource for beginning chemistry students, in particular the average and poor learners. Even for the good learners, the text book is a good starting point to learn about chemical concepts. Chapter two to five contain all the basic chemical concepts and chemical representations assessed in this study. Basic chemical concepts are sufficiently and precisely presented and well illustrated with multiple representations such as text and diagrams. Where necessary, multiple levels of representation are provided. A very good example is the reaction between sodium and chlorine to form sodium chloride on pages 83 and 85 (see *Appendix 26a*). Unfortunately, how text books are used in order to be effective educational resource depends to a great extent on the teachers and the learners. Chemistry teachers should be more aware of the change in the content and presentation of information in text books over the years, discard the old perception that text books are not good, and be able to use the text book more frequently and effectively in teaching and learning. The implementation of the program *Wajib Jawab (WAJA)* by the Perak Education Department beginning 2008 is an attempt to promote the use of text book among school teachers and learners. The importance of the chemistry text book is also reflected by the fact that definitions and diagrams in the chemistry text book and the accompanying practical workbook are now used as standard for answers in SPM chemistry examination.

Implication 8: Use teaching aids to teach abstract chemical concepts

Findings of the study show a strong correlation between developmental level and representational competence ($r=0.731$, $p<0.001$) as well as a moderate correlation between developmental level and understanding of chemical concepts ($r=0.575$, $p<0.001$). In addition, the regression model indicates that both understanding of chemical concepts and developmental level are important contributors to the variance of representational competence. Such findings imply that students need to possess a specific level of abstract thinking in order to understand chemical concepts as well as acquiring representational competence in chemistry. However, in this study, with a mean CTSR score of 9.29, and with only 10.42% of the subjects in the formal operational stage, teaching of abstract chemical concepts must be made more concrete to help learners who remain at the concrete operational stage (44.27%) or transitional operational stage (45.31%). Chemistry teachers should be aware of this factor and should try to introduce abstract concepts more concretely to beginning chemistry students. Hence, the use of 3-D models such as ball-and-stick models and computer simulations as teaching aids remains relevant. In this respect, selected sections from the chemistry teaching courseware when used appropriately may help these concrete learners visualize the unobservable underlying entities and processes. Assuming that all Form four students are formal thinkers would result in many learners merely acquiring a macroscopic view of chemistry and seeing only the surface features of representations.

Implication 9: Give more emphasis to laboratory work

Since the inception of the School-based Assessment for Practical Work or *Pentaksiran Kerja Amali Berasaskan Sekolah (PEKA)* in 1999, there is a marked decrease in the amount of time spent in the laboratory. Interview data from this study revealed some of the participants were unfamiliar with very common substances such as copper. Such finding highlights the need to incorporate sufficient laboratory time into chemistry lessons. In this respect, laboratory time is not confined to students carrying out experiments only. Laboratory work also includes short demonstrations conducted by teachers and actual physical substances shown to students. Learning should begin with the macroscopic where learners are expected to know the substance first, before going on to investigate the unobservable, underlying entities such as atoms (microscopic), and how to represent them (symbolic). Chemistry teachers should possess the necessary knowledge, skills and scientific awareness to enhance the meaning and relevance of science concepts to their students to help them reduce the gap between school and real life chemistry.

Implication 10: Review assessment question from time to time

Findings from the semi-structured interviews on multiple levels of representations show that submicroscocpic representations were not generated by any of the participant. 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, it appears this aspect of chemistry continues to be neglected in many chemistry classrooms. Findings of this study also indicate that students were able to score well on item that often appear in examination, even if such items were not easy. For example, the mean score for Part B of the TCR was higher (56.67%) compared to Part A (50.77%). This could be because items in Part A are rarely seen and almost never appear as examination item. In addition, in the TRC, the percent difficulty of items A2 and A5 were relatively low (see Table 5.20) although these items involved translation from one representation to another. This is because items involving the symbolic level frequently appear in examination papers. In fact, items like A2 and A5 are well-practised items. Such findings indicate the importance of assessment in determining what students will learn, or choose to learn. Hence, assessment items need to be reviewed in response to research findings from time to time. Beginning 2006, there appears to be a change towards the emphasis on testing at the particle level (Chemistry Paper 2, SPM, 2006). Chemistry teacher should be more aware of current trend and changes in assessment, be able to communicate the change to the learners, and ultimately such changes reflected through a change in chemistry instruction. Nakhleh (2002) not only suggested that submicroscopic representations be explicitly taught to the students but also emphasized to the students that such problems will be tested, and ensured that they appear in sufficient quantity to make it worthwhile for students to learn. The inclusion should be explicit and its importance manifested through assessment. The powerful influence of assessment on student behaviour is best summed up by Tobias:

> "Since examinations drive students' behaviour, efforts to modify curriculum and pedagogy without equivalent attention to modifying testing and grading practices are inadequate".
> (Tobias, June 29, 2000)

Despite the implications, the final decision on `how to teach' rests with the classroom teachers. This is because in reality, teachers are often faced with such constraints as overcrowded classrooms or laboratories, a compact chemistry curriculum, an educational system that is highly performance-driven, where teachers' success is often gauged on the number of students who score distinctions in public examinations. Within such a context, teachers are often left with little options other than to employ direct instruction. Although the desired achievement targets may be attained, there is no certainty that students learn with understanding.

7.3 Suggestions for Further Research

The findings of this study generally support the proposed theoretical and conceptual frameworks (see Chapters 3 and 6). However, this study also raises additional questions that should be pursued in future research. Several avenues for further research are suggested.

As this study to investigate representational competence of basic chemical concepts among Form four science students is relatively new in the local context, further research is necessary to establish the validity of the findings in this study. A replication of the study is recommended. This can be done by extending the research to Form four science students from other states in Malaysia.

Cross-age studies involving other levels of science students such as Form four, Form six, Matriculation, and undergraduates can be conducted. A comparison on students' representational competence of basic chemical concepts across the different levels may give more interesting findings.

Since data analysis at the preliminary stage of this study also revealed that 95% of the teachers surveyed (n=40) were unfamiliar with the term `chemical representations' and their uses in the teaching and learning of chemistry, similar studies to investigate pre-service chemistry majors and practicing chemistry teachers' understanding of chemical representations and to assess their representational competence of basic chemical concepts are also encouraged.

Useful insights and understanding into students' conceptions of chemical representations and their representational competence had been gained from the semi-structured interviews conducted in this study. Therefore, investigations involving a variety of qualitative research techniques such as classroom observations, inspection of students' written work (notes, exercises), analysis of documents (text books, reference books and work book), in-depth interviews, student-generated representations, and informal discussions with students and their teachers are highly recommended. Quantitative data alone provide limited insights.

A non significant finding between LAQ score and TRC score and between DSBT score and TRC score in this study should not be interpreted as "no relationship between these variables". The finding that alpha coefficient for the rote learning subscale was 0.47 while that of the meaningful learning subscale was 0.77 could imply internal inconsistency among items in the rote learning subscale. In addition, a non significant correlation between DSBT score and TRC score, as well as WM capacity (indicated by DSBT score) as a non significant predictor of representational competence, could be considered negative findings. Further research is necessary.

As the regression model generated in this study accounts for approximately 71% of the variance of representational competence, there is a possibility of other potential independent variable affecting representational competence being omitted from the set of independent variables studied. Further research could perhaps identify such relevant variable(s).

Since findings show substantial correlation between developmental level and understanding of chemical concepts ($r=0.575$, $p<0.001$) and the regression model shows that developmental level is as important as understanding of chemical concepts in influencing representational competence, perhaps the Classroom Test of Scientific Reasoning (CTSR) can be administered to all Form four science students to determine their developmental level, and indirectly, the ability to learn chemistry.

Finally, for classroom teachers who lack the time and resources to conduct conventional research, action research on students' representational competence of selected chemical concepts can be carried out during the course of teaching.

7.4 Conclusion

Findings of the study allow three broad categories of conclusion to be made.

Firstly, from the low overall levels of understanding of basic chemical concepts and the numerous alternative conceptions of chemical concepts identified from the TCC, it could be concluded that the subjects of this study did not possess adequate understanding of basic chemical concepts. This is indeed a cause for concern as understanding of chemical concepts is central to the study of chemistry.

In the absence of a sound mental picture of basic chemical concepts, there is no foundation upon which to build more advanced chemical concepts.

Although the overall level of understanding of chemical representations is at a satisfactory level, the high percent alternative conceptions of certain items identified from the TCR revealed students' poor conception of certain area(s) of chemical representation of matter. From these data, it could be concluded that the subjects of this study had limited understanding of chemical representations, as well as confusion between the three levels of representation of matter.

The overall level of representational competence is also unsatisfactory. Besides, majority of the subjects encountered difficulty interpreting chemical representations, making connections between representations and concepts, using representations to generate explanations, as well as translating between representations, in particular translating between different representations across levels. The generally unsatisfactory performance of the students in the TRC essentially says that knowledge and understanding of the three levels of representation of matter is not present in the LTM, or perhaps, is too fragmented to be useful.

Secondly, students' interview responses revealed limitations in several areas that are advantageous to enhance representational competence. For example: a lack of ability to visualize, describe or explain at the sub-microscopic level influenced their ability to interpret chemical representations at the submicroscopic level. It could be concluded that limited background knowledge and understanding of basic chemical concepts as well as the macroscopic, submicroscopic, and symbolic aspects of chemistry influenced students' interpretations of chemical representations at the various levels.

Thirdly, Pearson correlation coefficients of $r=0.745$ ($p<0.001$) between TCCt score and TRCt score, and $r=0.731$ ($p<0.001$) between CTSR score and TRCt score indicate that there is strong positive correlation between understanding of chemical concepts and representational competence, as well as between developmental level and representational competence. Meanwhile, a correlation coefficient of $r=0.575$ ($p<0.001$) between TCCt score and CTSR score indicate that there exists a moderate correlation between understanding of chemical concepts and developmental level. Furthermore, the regression model generated from the findings of this study had identified `understanding of basic chemical concepts' as the best predictor of representational competence, which alone accounts for 55.5% of the variance of representational competence. Another substantial contributor to the variance is developmental level (13.7%). In terms of explanation, the regression model shows that developmental level is as important as understanding of chemical concepts in influencing representational competence. This may explain why students with low level of understanding of chemical concepts (or low TCCt score) and low CTSR score commonly interpret chemical representations at a macroscopic level seeing only the observable.

As representational competence is a necessary skill to be acquired by every chemistry student, the findings therefore highlight the need to enhance understanding of basic chemical concepts among Form four science students before they proceed further in their chemistry course. Therefore, it is imperative that more time and effort be devoted to teaching basic chemical concepts as this lack of conceptual understanding could impede their representational competence. In addition, the teaching of chemistry should be made more concrete through the use of appropriate teaching aids so that abstract chemical concepts can be made more `visible' to learners who are not at the formal operational stage. This is crucial as findings of this study show developmental level not only influenced students' understanding of basic chemical concepts, but also their representational competence.

If the findings of this study were to have any practical significance, the implications and conclusion from the study need to be translated into real practice in the classroom.