An Exploratory Study of Tertiary Chemistry Students' Conceptual Knowledge

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Abstract

This study explored the conceptual knowledge of 1st year students majoring in chemistry from one of the universities in Singapore. In accord with the theoretical background, the aims of this preliminary study are to explore (i) the level of students' conceptual knowledge in basic chemistry, (ii) how classroom interaction and discussion sequence could help, and (iii) how questions can be used effectively in improving students' conceptual understanding; specifically in the areas related to chemical bonding and molecular structures. A pre-test was administered before any instruction was given to measure the subjects' prior knowledge. A post-test was conducted after students experienced one of three different instructional sequences. The three instructional methods consisted of group discussion, instructor's explanation and guiding questions. The questions used in pre- and post-tests were all conceptual questions. The results indicated that subjects were generally weaker in concepts leading to a particular molecular structure. Statistical analysis revealed little correlation between the module grades and concept test results. The performance of female and male students was also comparable. The three different instructional methods showed some impact in improving students' conceptual understandings but the results collected were not statistically significant.

Introduction

One of the main objectives in education is to develop higher level thinking in students including chemistry education. In order to achieve this, students' thoughts have to be stimulated to go beyond factual recall or algorithm activation. Most of the time, teachers assume that the underlying basic principles are well in place. Unfortunately, as many other researchers have also observed, this assumption fails (Nakleh, Lowrey & Mitchell, 1996). Students may know the principles but unable to make use of their logical connections. It has also been stated that there would be more concern about students' mastery of chemistry if exams were designed to test for depth of understanding (Moore, 1999).

In addition, research reveals that the most common impediment to problem solving is a lack of conceptual understanding (Herron, 1996). It was shown that students have far greater success answering traditional, mechanical questions as compared to conceptual questions (Nurrenbern & Pickering, 1987). One study reported that only ~38% of the students were successful in conceptual problems (Pickering, 1990). Another follow-up study also found that even good performers had difficulty with concept questions (Sawrey, 1990). These studies addressed an important issue in the core of chemistry education. A strong foundation in fundamental chemistry concepts is critical because students are expected to deal with more advanced and more complicated problems in higher courses and in real world. Therefore, it would be interesting to take a closer look at the students' achievements in introductory chemistry modules at the tertiary level.

Chemistry Concepts

The choice of topic for the conceptual understanding test designed for this study is chemical bonding and molecular structure. Students are introduced to these two concepts in high school and A-level chemistry. These concepts are reintroduced in undergraduate general chemistry courses. The reason behind this choice is that, the concepts of chemical bonding and molecular structure are essential towards understanding more complicated chemical reactions and chemical phenomena (Mortimer, 1997). There are a few fundamental concepts involved in bonding and structures, such as Lewis structures, electronegativity, bond polarity, hybridization, Valence Shell Electrons Pair Repulsion (VSEPR) and resonances. Therefore, students are likely to encounter novel questions which require the application of these fundamental concepts to solve.

Treatments

Effective Use of Questions as Learning and Assessment Tools: Effective questions should have three criteria (Hodges & Harvey, 2003). First, the questions developed must focus on a key learning goal. Second, the questions should be specific to a concept. Third, the questions should be multifaceted. In this way, patterns could be identified by checking the types of struggles that students were having with the course contents, and instructors will then be better able to design specific pedagogical interventions to address the issues.

Instruction and Discussion Sequence: The use of "classroom communication systems" (CCS) has been experimented by a few research groups to promote dialogue in classes. CCS technology claims to have shown improvements in conceptual reasoning. It was also reported that the type of dialogue and the discussion sequence have important effects on learning (David & James, 2003). The sequence involves cycles of short presentations, concept questions (tests), immediate feedback and peer group and/or class-wide discussion. Another study done by Joseph, Gayle and Marcella (1998) showed that class discussion encouraged the most class participation as compared to other instructional methods.

Purpose of the Study and Research Hypotheses

Given the limited time and resource, teachers are also held publicly accountable through standardized tests. Therefore, our efforts must create usable and powerful tools to support teachers' needs for efficiency as well as effectiveness in the development of student's learning. The aims of this pilot study are to explore (i) the level of students' conceptual knowledge in basic chemistry, (ii) how classroom interaction and discussion sequence could help, and (iii) how questions can be used effectively in improving students' conceptual understanding; specifically in the areas related to chemical bonding and molecular structures. This exploratory study examines the following research questions:

- Is student's conceptual knowledge related to module grades? (Research Question 1)
- Do students show better understanding of the concepts after group discussion? (Research Question 2)
- Do guiding questions and explanation help students to improve conceptual understanding? (Research Question 3)

Methodology

This study was divided into four parts. The first was to investigate the relationship between the undergraduate students' grades and their conceptual understanding in the topics mentioned. The subjects' grades in the general chemistry modules taken in the first semester were converted into numerical scores. The average score for these two modules is the variable "Average Module Score". This score is out of a maximum of 5 and was assumed to be a valid measure of the knowledge and the ability in solving basic chemistry exercises. It is understood that the final examination in a module is only a partial measurement of a student's knowledge. The score each subject obtained from the pre-test was the second variable, "Pre-Test Score".

The second part of the study was to identify which concepts or questions that students have difficulty in solving. When more than 50% of the subjects did not get the correct answer for that question, the concept involved was examined in more detail.

The third part of the study was to explore the efficiency and effectiveness of instruction /discussion sequence in improving conceptual understandings. Three different instruction sequences were employed. All the three different sequence groups were given the pre-test and the students had to complete these questions on their own. After which, they were allowed to discuss the questions in groups of three to four, randomly assigned. After discussion, the first sequence group received explanations and answers to the pre-test questions by the instructors, followed by a post-test. On the other hand, the second sequence group was given the post-test first, before any explanations and answers were given. For the third group, the instruction sequence was exactly the same as the first group, except that the third group also received a series of questions aiming to guide the students to reach the correct answer. In this case, the third variable was the “Instruction sequence”. Note that guiding questions were only given for one chosen question in the pre-test.

The final part of the study was to see if there were any statistical significant treatment differences among the three different instructional sequences using “Post-Test Score”.

The experimental group was year 1 students enrolled in the regular general chemistry courses in one of the universities in Singapore. These students had completed the basic chemistry modules in the first semester. They were invited to take part in the study through email after the examination. Fifty seven of them responded. Two of the students did not write their names in the question papers, therefore, the data obtained from these two students were excluded from the analysis that involved gender and module grades.

The study was carried out one month after the examination. It is assumed that all the students would have studied hard for the examination and their memories were still fresh at the time of this study. These students chose a time slot that was convenient for them. Groupings were non-systematically distributed. Forty four of them were female and eleven of them were male. The grades and test scores were processed by statistical methods even though the proportion of the representatives of both genders was not equal.

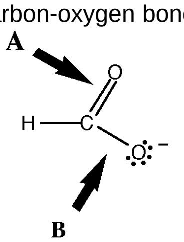
Instruments Used

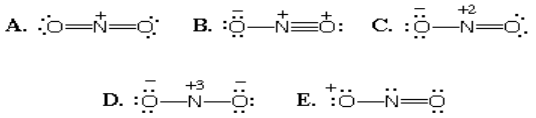
Both Pre-Test and Post-Test have 8 conceptual questions each, and all are multiple choice questions. The questions in the post-test were designed to be slightly more difficult than the pre-test. These questions have also been reviewed by two experienced lecturers from the university and they agreed that the questions were a good gauge in testing students’ understandings of fundamental concepts. The conceptual questions are selected from the following websites which focus on conceptual questions in chemistry:

(i) CONCEPT TESTS (http://www.jce.divched.org/JCEDLib/QBank/collection/ConcepTests/)
(ii) CHEMISTRY WEBERCISES DIRECTORY (http://www.wiley.com/college/webercises/)
(iii) BASIC CONCEPTS OF CHEMISTRY, Leo J. Malone, 6th ed., John Wiley & Sons, Inc., 2000 (http://college.wiley.com/Malone322474/resources/malone_site/Malone.htm)

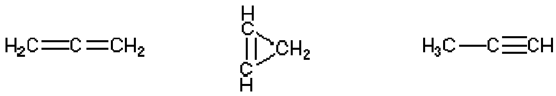
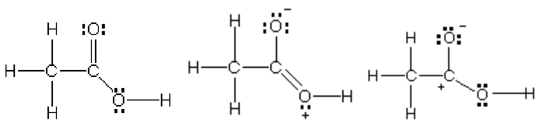
The questions, answers and fundamental concepts involved in each question of the Pre-Test and Post-Test are summarized as follows:

Pre-Test

S/N	Question	Answer	Concepts Tested
1	Only one of the following can exist with all four nuclei located in a single plane. Examine the Lewis structures to determine which one. **SO_3** **SO_3^{2-}** **$SOCl_2$**	SO_3	• Draw a Lewis structure • VSEPR • Molecular geometry
2	Ethylene, $H_2C{=}CH_2$ is planar. What is the structure of allene, $H_2C{=}C{=}CH_2$? **Planar** **Staggered** **Others**____________	Staggered	• Hybridization • π-bond formation • Molecular structure
3	One of the two equivalent energy resonance structures for formate anion is shown below. Which carbon-oxygen bond is longer? **A** **B** **Both are equal** 	Both are equal	• Resonance • Bond strength and bond length
4	What is the H-C-H bond angle of CH_3^+ (a carbocation)? **90^o** **109.5^o** **120^o** **180^o** **Others:** ___________	120^o	• VSEPR • Molecular geometry • Bond angles

S/N	Question	Answer	Concepts Tested
5	Nitrous oxide (laughing gas, N_2O) could have two sequences of bonding; the symmetrical NON and the unsymmetrical NNO. Based on the formal charges for these two, which sequence should be the right structure? **NON** **NNO** **Can't select because ______**	NNO	• Draw a proper Lewis structure • Rules of formal charges
6	Which Lewis dot structure for NO_2^+ has the lowest energy? 	A	• Rules of formal charges
7	Which bond is stronger? Why? **O=O** **S=S** **Reason**(s): _________	O=O Smaller, better p-p overlaps	• Factors affecting bond strength. • Size of atoms, overlapping of orbitals
8	Consider the following molecules and select those that are polar. Explain. **ClF** **ClF_3** **ClF_5** **Reasons(s): ____________**	All	• VSEPR • Molecular geometry • Bond polarity • Dipole moment

Post-Test

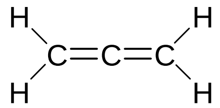
S/N	Question	Answer	Concepts Tested
1	For the three isomeric C_3H_4 hydrocarbons shown below, which one(s) can exist with all the carbon and hydrogen nuclei located in a single plane? 	None	• Hybridization • π-bond formation • Molecular geometry and structure
2	What is the structure of cumulene, $H_2C{=}C{=}C{=}CH_2$? Planar Staggered Others________	Planar	• Hybridization • π-bond formation • Molecular geometry and structure
3	What is the H-C-H bond angle of • CH_3 radical? **90^o** **109.5^o** **120^o** **180^o** **Others: ___________**	120^{o}	• VSEPR • Molecular geometry • Bond angles
4	Would the hydrogen in hypochlorous acid (HClO) be covalently bonded to the chlorine or the oxygen? **Chlorine** **Oxygen**	Oxygen	• Draw a proper Lewis Structure • Bond strength
5	Which of the following resonance structures is lowest in energy?  A B C	A	• Formal charges • Resonance
6	Which bond is stronger? Why? **O-O** **S-S** **Reasons:** ___________________________	S-S Bigger, less electron repulsion	• The factors affecting bond strength: • Size of atoms, lone-pair electrons repulsion etc
7	Which molecule has a smaller dipole moment? **$Cl_2C{=}O$** **$H_2C{=}O$**	**$Cl_2C{=}O$**	• VSEPR • Molecular geometry • Bond polarity • Dipole moment
8	Consider the following molecules and select those that are nonpolar. Explain. **XeF_4** **SF_4** **SiF_4** **Reasons:** _________________	**XeF_4 and SiF_4**	• VSEPR • Molecular geometry • Bond polarity • Dipole moment

One point to note is that, more than one concept was incorporated in most of the questions in both pre-test and post-test. Therefore, mastering of one particular concept is definitely not sufficient to answer these questions. Students have to make use of the different concepts learnt, and also assimilate and apply the concepts appropriately in order to get the right answer. To encourage greater participation, it was stressed that subjects did not need to revise prior to the test and it was fine to leave blanks for those questions which they did not know or not sure.

Guiding Questions

Question 2 from pre-test was selected to have the guiding questions because it is slightly more difficult as compared to the rest. First of all, students must know the relationship between molecular geometry and hybridization. Second, they have to know the criteria for formation of π-bond and how the orientation of the orbitals with respect to each other. Lastly, they have to deduce the overall structure of the molecule. The guiding questions were presented verbally during the instructor's explanation portion and only continued to the next guiding question when subjects got the correct idea.

The instructors drew a schematic diagram of allene and then proceed to ask the guiding questions:



1. What are the hybridizations for the three carbons?
   Ans: The two carbons at the end are sp^2 hybridized. The central Carbon is sp hybridized.
2. When a carbon is sp^2 hybridized, what is the geometry of these sp^2 hybridized orbitals?
   Ans: Trigonal planar
3. When a carbon is sp^2 hybridized, what is the position of the un-hybridized p-orbital relative to the plane?
   Ans: They are perpendicular to each other.
4. How does a π bond form?
   Ans: Side-way overlapping of p-orbitals which are parallel to each other.
5. When a carbon is sp hybridized, what is the geometry of these sp hybridized orbitals?
   Ans: Linear
6. When a carbon is sp hybridized, what are the positions of the un-hybridized p-orbitals relative to the line of the sp-orbitals?
   Ans: The two un-hybridized p-orbitals are perpendicular to each other, which are also perpendicular to the sp-orbitals.
7. When a π bond is formed between Carbons 1 and 2, which p-orbital on Carbon 2 will be used?
   Ans: The one parallel to the un-hybridized p-orbital of carbon 1.
8. Which p-orbital on Carbon 2 will be used to form π bond to Carbon 3?
   Ans: Another p-orbital from Carbon 2, that is perpendicular to the previous p-orbital which has already formed a π bond with Carbon 1.
9. How is the trigonal plane of Carbon 3 arranged with respect to the trigonal plane of Carbon 1?
   Ans: The two planes are perpendicular to each other.
10. What is the shape of allene?
    Ans: Staggered

Administration of Tests

The study was implemented over one 90-minute session. Subjects were asked to take 10 minutes to answer the pre-test questions. About 30 minutes were allocated for the group discussion. The instructor used about 15 to 20 minutes to go through and explain the pre-test questions. Another 10 minutes were given to the students to complete the post-test. Longer time was given in each session when there were requests from students.

Results and Discussions

Correlation between Grades and Conceptual Understanding

The Pearson's Correlation Coefficient test was carried out to see if there is any correlation between the various variables. There is a weak positive correlation (r = 0.253) between the Pre-Test

Scores and the Average Module Scores. However, at the 95% confidence level, there is no significant correlation between the two variables (Sig. = 0.062). Similar conclusion is drawn between the Post-Test Scores and the Average Module Scores (r=0.009, Sig. = 0.950).

In the past, good examination grades were believed to be a good indication that the students had achieved solid understanding of the materials. Lately, many educationists suggested otherwise, i.e. good examination grades do not always reflect good grasp of the subject materials, as mentioned by Huitt (1998), *"Old standards of simply being able to score well on a standardized test of basic skills, though still appropriate, cannot be the sole means by which we judge the academic success or failure of our students."*

From the result obtained in this study, there was no significant correlation at 95% level of confidence between examination performance and the pre- and post- tests' performance. These data further supported the statement that, good examination grades do not always imply good understandings. Nevertheless, we would not exclude other possible reasons such as:

(i) Subjects had more time in preparing for examinations and usually put in more effort in answering examination questions as compared to the pre- and post- tests in this study.
(ii) Some subjects had forgotten most of the materials even though the gap between the examination and this study was merely one month.
(iii) Many other topics were included in the examinations, such as chemical equilibrium, kinetics, acid-base chemistry etc. Some subjects may be expert in these other topics but weak in the concepts covered in the study.

Gender difference

Anova analysis shows that there is no statistical significant difference between male and female subjects in the Average Module Score (F = 0.269, Sig. = 0.606), Pre-Test Score (F = 1.988, Sig. 0.164) and Post-Test Score (F = 0.405, Sig. = 0.527).

Conceptual Understanding, Learning Approach and Reasoning Skills

A breakdown of Pre-Test and Post-Test scores by question was done and the data are summarized in Table 1. It is also found that about 50% (or more) of the subjects did not get the correct answers in 4 out of the 8 conceptual questions in the Pre-test. These questions are questions 2, 3, 5 and 8. Question 2 is the worst answered, only ~5.3% of the subjects got it right.

Similar to the pre-test result, more than 50% of the subjects did not get the correct answers in 4 out of the 8 conceptual questions. These questions are questions 1, 2, 3 and 8. This implies that a majority of the subjects may have difficulties grasping the concepts or may still have a misconception, even after group discussion and explanation.

From the data, it becomes obvious that some of the subjects might have difficulty in drawing appropriate Lewis structures, and most of them are pretty weak in the fundamental concepts such as hybridization, molecular geometry and structure, resonance, valence shell electron pair repulsion (VSEPR) and bond polarity.

As pointed out by Granville (1985), educators often tell students that an effective way to study is through working problems because they get to review the principles involved. Unfortunately, students tend to adopt the attitude that arriving at the correct answer is more important than understanding it. They would rather look for key words in the question that link to what they have already practiced with. To them, this approach is more convenient, easy, and faster. In such a situation, students are likely to lose the clear review of the principles and concepts involved. When dealing with unfamiliar observations, students who rely heavily on mastering familiar questions to cope with chemistry modules may have a problem assimilating and accommodating their prior understanding. Sawrey (1990) also attributes the failure to answer conceptual questions to the "drill work" approach students take, which causes the qualitative and conceptual side of the discipline to suffer.

Table 1: Summary of Students' Answers in Pre-Test and Post-Test

		Others		**Wrong Answer**		**No Answer**		**Correct Answer**	
		Count	%	Count	%	Count	%	Count	%
Pre-Test Question	1			8	14.0%			49	86.0%
	2	8 [a]	14.0%	39	68.4%	7	12.3%	3	5.3%
	3			30	52.6%	1	1.8%	26	45.6%
	4			9	15.8%	1	1.8%	47	82.5%
	5	11 [b]	19.3%	19	33.3%	8	14.0%	19	33.3%
	6			12	21.1%	3	5.3%	42	73.7%
	7			2	3.5%	5	8.8%	50	87.7%
	8			26	45.6%	2	3.5%	29	50.9%
Post Test Question	1			29	50.9%	10	17.5%	18	31.6%
	2	2 [a]	3.5%	27	47.4%	1	1.8%	27	47.4%
	3			42	73.7%	2	3.5%	13	22.8%
	4			14	24.6%	1	1.8%	42	73.7%
	5			7	12.3%	1	1.8%	49	86.0%
	6			9	15.8%	3	5.3%	45	78.9%
	7			20	35.1%			37	64.9%
	8			39	68.4%	4	7.0%	14	24.6%

Footnote
a: The subjects thought the molecule was neither planar or staggered, but suggested different structure to the molecule.
b: The subjects explained why they were unable to determine which was the correct answer.

We predict that subjects who rely a lot on memory work and practicing exercises to score lower in the concept test, while those who seek to understand the concepts and only memorize selective contents will have better conceptual understanding and will get higher scores.

We should be cautious that, the ability to apply the concepts learnt and a lack of conceptual understanding or body of knowledge are different. From the subjects' responses in the tests, many subjects' failure to get the correct answer could be due to a lack of knowledge and conceptual understanding or an inability to apply the concepts learnt. For example, a few subjects did not get the correct answer for question 6 of pre-test because they were not familiar with the formal charges rules. This is a lack of knowledge that hinders the answering of other questions which require formal charges rules. Some subjects were able to exercise reasoning skills, but were sabotaged by misconceptions. For example, in question 5 of pre-test, some subjects chose "can't select because the two sequences have zero formal charges on all atoms". They arrived at this answer because the Lewis Structures that they drew had atoms that did not fulfill octet rules. They constructed this misconception probably because they had the idea that not all atoms have to follow octet rules because some compounds, such as NO_2 is a radical with the N atom having seven electrons only.

Instruction Sequence and Approaches

As mentioned by David and James (2003), there are two reasons for starting the concept test prior to any instruction or peer discussion. First, the requirement to make an individual response meant that they were forced to think about the problem, and to formulate their own reason for their selected answer. In contrast, with an initial peer discussion the students felt that they might be more likely to be passive, and be influenced by the more confident students, and more likely to acquiesce and accept the dominant interpretation without much thinking. Second, having constructed their own answer, students felt they benefited more from the subsequent peer discussion. They would be more likely to engage in dialogue and to provide reasons for, and defend their ideas and they would be more likely to be able to identify gaps in their thinking. In this way, the more knowledgeable students could help those less advanced students to achieve higher levels of conceptual acquisition. This study also pointed out that it was important for the teacher to tell the right answer and clearly explain the reasons at the end of the session.

According to the study done by Joseph, Gayle and Marcella (1998), class discussion encouraged the most class participation as compared to other instructional methods such as traditional lecturing, cooperative learning (i.e. group discussion in this study) and concept mappings. In the class discussion format, the instructor asked conceptual or higher-order questions directly to the students in the classroom. During the session, leading questions were used to probe and guide students' thinking. This involved active dialogue between the students and the instructors. This class discussion format is similar to Instruction Sequence 3 in this study whereby guiding questions were given.

However, there are also some potential problems in this type of teaching approach. Asking question in a class and waiting for volunteer to answer normally invites silence. In addition, some students do feel uncomfortable in silence and some may have even gone to dreamland. On the other hand, calling individual student may also provoke more fear than thought. Some students consider being questioned a trap for them to look ignorant in public (Felder R., 1994). For this method to be successful, students should feel comfortable being questioned in classroom. They must also be able to take it easily when their answers or concepts are being challenged. Therefore, various personalities of students should not be overlooked in this case especially in Singapore, where most students are considered more reserved and shy as compared to students from western countries. Therefore, cooperative learning among peers would be the next better choice.

The impact of the different instruction sequences in improving conceptual understanding was analyzed by checking the difference in pre- and post-test scores against the three instruction sequence groups. Instruction Sequence Group 2 gives a slightly higher mean value in this case, as indicated in the summary shown in Table 2. However, Anova analysis shows that the means of the Difference in Pre- & Post-Test Scores of the three instruction sequence groups indicate no significant difference (F = 1.760, Sig. = 0.182).

Table 2: Statistics of Difference in Pre- & Post-Test Scores and Instruction Sequence

Instruction Sequence	Mean	N	Std. Deviation	Grouped Median
1	-.6667	36	1.80476	-.5833
2	.5000	14	2.59437	.5000
3	-.4286	7	1.27242	-.3333
Total	-.3509	57	2.00438	-.2500

A few questions in the tests are related to three-dimensional molecular structures. Research shows that students achieve the best results when they use concrete, and pseudo-concrete types of representations (e.g. three-dimensional models, their photographs, computer-generated models.) while the use of more abstract types of representations (e.g. schematic representations, stereochemical formula) are less effective (Vesna, F., Margareta V. 2003). This may explain why in this study not much improvement was seen after instructor's explanation and group discussion. Concrete or pseudo-concrete representations were not utilized while only schematic representations were used in this study.

Implications for Chemistry Education

The purpose of chemistry education is to train students to solve novel problems within the discipline. This aim will fail terribly if students continue to rely on rote learning, routine exercise solving and memorization of content to master the subject. Emphasis should be put in training students to think critically in novel situations. However, good reasoning skills and logical thinking may still fail to solve novel problems due to a lack of basic knowledge or essential concepts. As mentioned by O'Brien (2000), if students are having trouble solving problems, the first thing to check is their understanding of the concepts in the problems. Therefore, educators should help students to build a strong foundation in chemistry. Fundamental chemistry concepts must be reinforced and any misconception should be rectified as early as possible. It is noted that, conceptual change at a later stage is far more difficult to achieve (Martina, 2001)

Research has shown that students learn by different methods (Willemsen, 1995 and Lenehan, 1994). Joseph, Gayle, and Marcella (1998) also pointed out that multiple and varied teaching methods could satisfy the diverse learning needs of students, and thus should be able to improve the overall standard of meta-cognitive skills, which is the main goal of education. Therefore, educators and instructors should present the materials in different ways to the students, so that the concepts are reinforced and the mastery of the material could be achieved easier.

Last but not least, a change in assessment strategy might be necessary in chemistry education. Most often, the content covered in a module is very broad and a bit too much for students to cope. In this case, students tend to choose the easier way out, which is to simply master the factual content instead of seeking to understand and apply the concepts. If assessment methods can be changed to an open-book style (in final examination, project-based learning etc.), with greater emphasis on checking the students' conceptual understandings, the abilities to apply concepts and to solve novel problems, students may shift their attention from memorizing factual content to mastering concepts.

Limitations Encountered and Recommendations for Further Studies

The limited number of subjects and the unequal numbers of subjects in each group put a constraint on the validity of this pilot study. More subjects should be included for satisfactory quantitative data analysis. The subjects should be randomly assigned to the different treatment groups.

Another limitation of this study is the lack of a control group (i.e. absent of any instruction sequence that involved group discussion, instructor's explanation and guiding questions). Therefore, the actual impact of each component in the instruction sequence was not determined. A more refined cycle of instruction sequence should be developed to get a clearer picture on the effectiveness and efficiency of each treatment component. The number of treatment sessions could be increased so as to improve the power of the intervention.

The total number of conceptual questions used in this study for investigating the conceptual understanding of students in these topics (i.e. bonding, structure and resonance) may not be sufficient. On the other hand, setting more questions that encompass all the fundamental concepts in these topics would mean more time is needed by the subjects. Therefore, a well crafted test is crucial in this type of study. More questions could be designed to focus on fewer fundamental concepts that would help us to identify more clearly the general weak points of students. Detailed in-depth interviews with subjects could help to compensate this limitation because more representative views could be obtained. This qualitative data can help to reveal the thinking and cognitive process of the subjects, including any misconceptions or difficulties in understanding certain concepts.

Group discussion should be properly guided by the instructor to avoid any domineering effect. As some introvert students may just take passive participation without voicing out their own ideas. Subject's unfamiliarity with other members could also be the reason of passiveness in the discussion. A short ice-breaking session could be included.

The results of the study also show that there is a need to emphasize more these fundamental concepts, e.g. Lewis structures, hybridization etc.

Conclusion

It has been shown that a weak correlation exists between the module grades and conceptual understandings. There is no significant difference between the performance of female and male students. Subjects are generally weaker in concepts leading to a particular molecular structure. Different discussion and instruction sequences show some impact in improving students' conceptual understandings but they are not statistically significant. Guiding questions seem to help but not conclusive probably due to the small sample size.

References

Bodner G.M. & Herron J.D. (1986) Constructivism: A theory of knowledge. *Journal of Chemical Education*, 63, 873

David J.N. & James T.B. (2003) Peer instruction versus class-wide discussion in large classes: a comparison of two interaction methods in the wired classroom. *Studies in Higher Education*, 28(4) 457-472

Felder, R. (1994) Any questions. *Chemical Engineering Education*, 28(3), 174-175

Granville, M.F. (1985). Student misconception in thermodynamics. *Journal of Chemical Education*, 62(10), 847-848

Herron, J.D. (1996) The chemistry classroom: Formulas for successful teaching. American Chemical Society, Washington D.C., 83-160

Hodges, L.C. & Harvey, L.C. (2003) Evaluation of student learning in organic chemistry using the SOLO Taxonomy, *Journal of Chemical Education*, 80 (7), 785-787

Huitt, W. (1998) Critical thinking: An overview. *Educational Psychology Interactive*. Valdosta, GA: Valdosta State University. Retrieved, http://chiron.valdosta.edu/whuitt/col/cogsys/critthnk.html.

Joseph, S.F., Gayle N. & Marcella T. (1998) Integrating multiple teaching methods into a general chemistry classroom. *Journal of Chemical Education*, 75 (2), 210-213

Lenehan, M.C.; Dunn, R.; Ingham, J. (1994) Effects of learning-style intervention on college-students achievement, anxiety, anger, and curiosity. *Journal of College Student Development*, 35, 461-466

Martina N. (2001) Problems and possibilities for learning in an introductory chemistry course from a conceptual change perspective. *Science Education*, 85, 158-179

Moore, J.W. (1999) Do we value learning? *Journal of Chemical Education*, 76(1), 5-5

Mortimer E.F. (1997) Beyond chemical boundaries: A conceptual profile for molecule and molecular structure. *Quimica Nova*, 20 (2), 200-207

Nakleh, M.B.; Lowrey, K.A.; Mitchell, R.C. (1996) Narrowing the gap between concepts and algorithms in freshman chemistry. *Journal of Chemical Education*, 73(8), 758-762

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

O'Brien, P. (2000) The use of cognitive ability testing to set targets, in Sears, J. Sorensen,P. (ed), *Issues in Science Teaching*, RoutledgeFalmer, New York, 114-122

Pickering, M. (1990) Further studies on concept-learning versus problem solving. *Journal of Chemical Education*, 67(3), 254-255

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

Vesna F., Margareta V. (2003) Students' understanding of molecular structure representations. *International Journal of Science Education*, 25(10) 1227-1245

Willemsen, E.W. (1995) *New Direction in Teaching and Learning*. 61, 15-22

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