

EFFICACY OF INTEGRATING STS APPROACH IN IMPROVING STUDENTS' CONCEPTIONS ON THE MOLE CONCEPT

Louie B. Dasas^{1,2}, Conrad Capule¹, Donn Yves Geronimo¹, Dominick Ranay¹, Dayanara Balanday¹, Angela Bunao¹, Paolo Arroyo¹, Ivan Keanu Espiritu¹

¹College of Education, University of Santo Tomas, Manila Philippines

²College of Education, University of the Philippines Diliman, Quezon City Philippines
dasaslouie@gmail.com

ABSTRACT

Chemistry is one of the hardest and most challenging subjects in high school and college Science (Marais & Combrinck, 2009; Passmore, Stewart, & Catier 2009; Taber, 2011). Probably one reason why students find Chemistry hard is because understanding it would mean relying on making sense out of the invisible and the untouchable Kozma & Russell, 1997). This study investigates on the efficacy of integrating Science-Technology-Society (STS) approach in improving students' conceptions on the Mole Concept. This study is deemed significant to Science Education and its stakeholders as it aims to alleviate misconceptions of the students on the Mole Concept, which is a fundamental topic in Chemistry. An Understanding by Design (UbD) unit plan on the topic Mole Concept was developed, content validated. An intact class of Grade 9 students served as participants of the study. Mole Concept Test (MCT), and Mole Concept Checklist (MCC), Initial-Revised-Final Ideas (IRF) charts, student reflection logs, and the implementing teacher's daily journal were means to gather pertinent quantitative and qualitative data. The results obtained suggest that there was a significant improvement on students' conceptions on the Mole Concept as revealed by the results of the paired samples t-test, weighted mean ratings in the MCC, students' responses in the IRF charts and reflection logs as well as the implementing teacher's journal entries. The improvement of students' conceptions on the Mole Concept suggests the efficacy of using the STS approach in teaching.

Field of Research: science education; Mole Concept; STS

1. Introduction

Science education has been the center of many educational reforms which aims to make Science more social and less exclusive but much of the reformist's dismay, the call for reform in the way science is taught in schools have been going on for quite some time now but little progress have been made. Despite reforms, there is still a persisting concern about students' conceptions and means to better improve student achievement in Science subjects. Chemistry remains as one Science discipline that students perceive as difficult to grasp (Johnstone, 2000). Stoichiometry is an important topic in Chemistry and one of the concepts central to the learning of Chemistry is the Mole Concept (Dahsah et. al, 2008). However, literature suggests that students frequently hold alternative conceptions on Stoichiometry concepts, and that they often experience difficulties learning Stoichiometry (Boulaoude&Barakat, 2000). This study explores on the efficacy of using the STS approach in teaching the Mole Concept.

2. On the Mole Concept

Chemistry is one of the hardest and most challenging subjects in high school and college Science (Marais & Combrinck, 2009; Passmore, Stewart, & Catier 2009; Taber, 2011) Students often have a hard time in Chemistry because the subject does not *seem* to have direct implications to students and the society. Because of this, many students find Chemistry as irrelevant and boring, mainly

because their instruction is out of synchrony with the world outside of school (Aikenhead, 2003). With demotivating perceptions of Chemistry, pupil interest and achievement in Chemistry has declined over the decades (Osborne & Collins, 2000).

The adoption of the fundamental value for the amount of substance by the scientific community stems from the acceptance of the Atomic Molecular Theory of matter in interpreting chemical changes (Brock, 1967; Rocke, 1984; Thuiller, 1990; Furio et. al., 2000). This theory puts into focus on the relationship between amounts of particles involved in reactions. The huge amount of microscopic particles of such substances makes it difficult to count them directly at the microscopic level (Furio, et. al., 2000). The relevance of Avogadro's number is used to relate these minute particles by number and mass to larger, more observable quantities. It is used as a scaling factor in representing microscopic masses in macroscopic quantities. The introduction of the amount of substance as a new quantity makes counting elementary entities from the masses of reacting substances at the microscopic level possible.

It must be noted that the study of the Mole Concept wasn't easily understood by students both in the high school and university levels. Garcia (1990) administered out a survey using a large student sample from secondary education to first-year university course. They reported an increased proportion of wrong answers concerning the Mole Concept, that is, answers that differ from the International Union of Pure and Applied Chemistry (IUPAC) definition. They concluded that there was a superficial learning of the concept (Furio et. al., 2002). In a study conducted by Dierks in 1981, he found out that the main learning difficulties of students' were the abstract character of the expression 'amount of substance' and the diverse meanings attributed to the word 'mole'. In short, there is a misunderstanding between the IUPAC definition of the mole and that of the students' definition. In another study conducted by Cervellati in 1982, he and his group found out that secondary (high school) students perceived the mole as a mass, and did not use it as a unit of the 'amount of substance'. Furthermore, possible causes for students' failure were identified such as inadequate content of the curriculum, the methodology of instruction used, the system of evaluation and the training of educators. Gabel and Sherwood (1984) developed a test on the Mole Concept which focused on using more familiar names such as sugar and oranges replaced chemical names of the substances, and where the term 'dozen' replaced that of 'mole'. The results suggest that there is difficulty in the resolution of problems that are linked to the use of the term 'mole' and of other unfamiliar terms rather than the understanding of the concepts of volume, mass, and set of particles.

3. Science, Technology, and Society (STS) as an Approach to Teaching

Recent Science education reform efforts have focused on Science instruction that enhances student understanding of the nature of science, enabling them to critically analyze scientific information as well as to apply it in real-life situations, and sets them on a path of life-long learning in science (Dass, 2005). One example of reform in Science education is the STS approach. The Science/Technology/Society (STS) approach is defined by the National Science Teachers Association (1991) as the "teaching and learning of science and technology in the context of human experience." More specifically, the bottom line in STS is the involvement of learners in experiences and issues which are directly related to their lives. STS develops students with skills which allow them to become active, responsible citizens by responding to issues which impact their lives. The experience of Science education through STS strategies will create a scientifically literate citizenry for the twenty-first century (Dass, 2005).

The STS approach offers several important benefits including real world experience and relevance to the student's life, but most importantly, STS creates a context in which students find themselves with a need to learn and a use for what is learned. The STS approach to teaching Science has a very

clear benefit to the way that Science is taught (and hopefully learned). By making Science a student-generated problem-based endeavor, it becomes more interesting and relevant for students. If students take ownership of the learning process, they are more inclined to pursue a topic in greater depth and retain the knowledge longer (Ackay and Yager, 2013)

4. Theoretical Framework

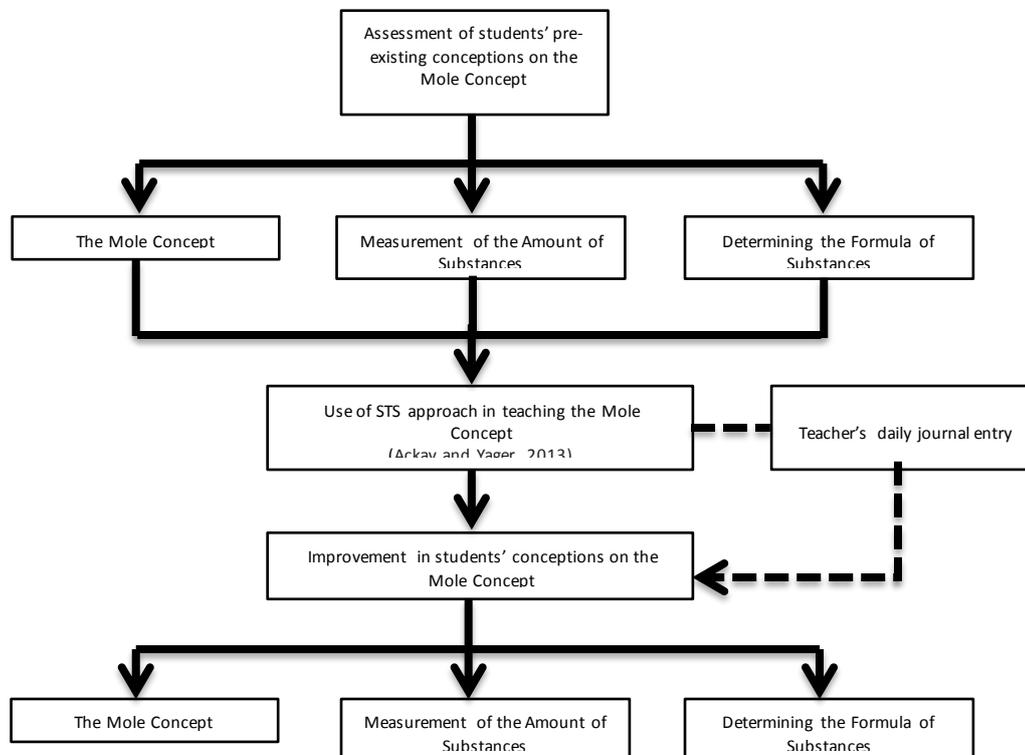


Figure 1. Theoretical framework of the study.

As reflected in Figure 1, the study aims to examine the efficacy of using the STS approach in teaching the Mole Concept. More specifically, the study regards the following specific questions for investigation:

- 1) What are the prior conceptions of the students with regard to the Mole Concept- the Mole Concept; Measurement of the Amount of Substances; and determining the formula of substances?
- 2) Is there a change in students' conceptions about the Mole Concept after exposure to teaching using the STS approach?

5. Methodology

5.1 Sample and data collection method

The participants for this research were forty-seven (47) Grade 9 students from a laboratory school. Before the use of the STS approach, the participants subjected to pre-test using the Mole Concept Test (MCT) and the Mole Concepts Checklist (MCC). Also, the initial ideas of the students were assessed using the IRF chart. During the implementation of the lesson using the STS approach, the implementing teacher kept a daily journal to record significant highlights of the day's session. The participants were made to accomplish the MCT and MCC at the end of the lesson. In addition, reflection logs and IRF charts were used to obtain qualitative data which focuses on students' final ideas about the Mole Concept. The study made use of a mixed method research design. The results of the MCT were analyzed using paired t-test while the students' responses in the MCC were

subjected to descriptive statistics. Qualitative data obtained from IRF charts, reflection logs, and implementing teacher's daily journal entries were used to enrich the discussion.

5.2 Instrumentation

The study made use of a researcher-developed Mole Concept Test (MCT) which comprises forty-six (46) items. MCT was found to have the Cronbach-alpha of 0.74. In addition, the Mole Concepts Checklist (MCC) was used to further examine improvement of students' conceptions. The MCC was adapted from the Life Energy and Processes Concepts Checklist constructed by Dasas (2013). The concepts checklist composed of five scales: 5- Comprehensive, 4- In-depth, 3- Vivid, 2- Apparent, and 1-Limited. These scales are accompanied with corresponding descriptors based on the six facets of understanding rubric designed by Wiggins and McTighe. The MCC was pilot tested and obtained the Cronbach coefficient alpha of 0.90. The researchers used the results gathered from MCC to further analyze students' conceptions about the Mole Concept. The implementing teacher's daily journal entries, IRF charts and reflection logs were used to enrich data analysis.

6. Findings & Discussion

6.1 Result of the pre- and posttest

As expected, the post-test scores of the samples are higher than their pre-test scores. It could be said that majority of the students had improved mean scores in the post-test. However, it may be noted that majority of the students had mean scores below 50% of the total number of items. There were few students who had a mean score that was 50% of the total number of items.

Table 1. *Standard deviations, Cronbach alpha, standard error of measurements, and standard error of difference of the pre-test and post-test.*

	Mean	N	SD	Cronbach Alpha	SEM	SED
Pre-Test	12.5532	47	3.54357	0.59109	0.51688	0.671578 (2)= 1.343156
Post-Test	17.62	47	2.95	0.907681	0.43	

It can be gleaned from Table 1 that all the students who obtained a gain score of 1.343156 or higher from pre-test to post-test had a significant gain in the post-test. The standard error of difference was multiplied by 2 to get a 95% probability to make the result more stringent. It was found that 37 students or 78.72% had significant gains in the post-test. On the other hand, there were 10 students or 21.28% who did not post a significant gain in their scores. Based on these results, it could be said that majority of the students had significant gains in the post-test. To further enrich the abovementioned findings, the researchers utilized a two-tailed paired sample t-test for dependent means since the mean scores belong to the same group of students.

Table 2. *Paired Sample t-test for the Difference between Pre-test and Post-test Scores of Students in the Mole Concept Test.*

	Mean	N	Mean Difference	Std. Deviation	t	Sig. (2-tailed)	Interpretation
Pre-Test	12.5532	47	-5.02128	3.54357	-8.129	.000	Highly significant
Post-Test	17.5745	47		2.93957			

Table 2 shows the paired sample t-test for the difference between the students' mean scores in the pre-test and post-test. It could be deduced that there is a significant difference between the pre-test and post-test as reflected by the t-value of -8.129. The t-value is negative because the mean

difference has a negative value. This would suggest that the post-test mean score is greater than the pre-test score. The difference is highly significant at 0.05 level of significance such that the Sig. value .000 is less than 0.05.

6.2 Students' conceptions on The Mole Concept

It could be glanced in Table 3 that the item describing the significance of the Avogadro's number recorded the highest weighted mean of 4.30. On the other hand, the item on how the Mole Concept was developed had the lowest weighted mean of 3.85. The students rated their understanding of the Mole Concept with focus on the items enumerated above as In-depth.

Table 3. Results of the MCC on the sub-topic The Mole Concept

Item	Weighted Mean	Description	Standard Deviation
a) how the Mole Concept was developed	3.85	In-depth	0.98
b) the significance of the Avogadro's number	4.40	In-depth	0.80
c) the mole as a fundamental unit in measuring the amount of substances	4.30	In-depth	0.88
d) the relationship between mole and Avogadro's number	4.19	In-depth	0.85

Based on the reflection logs, the students had correct understanding of the definition of a mole. Clearly, the students thought of the "mole" as a fundamental unit of measuring the amount of small objects. Also, they were able to provide very interesting associations to the unit of mole such as "dozen of eggs", "pair of shoes", or "box of sardines". Similarly, students were able to describe the mole as the number of particles in a substance which uses the Avogadro's number (6.02×10^{23}). It could also be noted that there were significant responses of the students on the question pertaining to the importance of the Mole Concept. 62% of the students were able to provide correct conceptions on how/why the Mole Concept is important. Most the students state that the importance of Mole Concept is to provide an easy, more convenient way of counting or measuring the number of atoms in a given substance.

The abovementioned findings from the reflection logs are in consonance with the responses made by the students in the IRF charts. Prior to the integration of STS approach in teaching, some students had naive ideas pertinent to the Mole Concept. Some students described the mole as "another way of combining elements" and the "study of molecules". Later on, students were able to refine these ideas into more correct conceptions. The students were able to surface the use of the Avogadro's number as well as the concept of mole representing the number of particles. However, it must be noted that there is a good number of students that had correct initial ideas that the mole is "measures the amount of substances". This may be indicative that students had prior understanding and/or exposure of the Mole Concept. It can be observed that the same conception recurred as Final Ideas. Also, the students were able to realize that the Mole Concept is "used to find the amount of amu".

6.3 Students' Conceptions on Measurement of the Amount of Substances

Table 4 reflects the different items that describe the sub-topic, Measurement of the Amount of Substances. Based on the data above, it could be said that students have rated their understanding of the items a1, a2, and c3 as Comprehensive. This suggests that students may have understood how to determine the atomic mass of elements and compounds and as well as how to solve for molar mass. On the other hand, the students had a weighted mean rating of 3.98 on the item which pertains to the difference between and among molar quantities. The students had a rating of In-

depth to describe their understanding of all the other items (b1, b2, b3, c1, c2) which fall under the sub-topic Measurement of the Amount of Substances.

Table 4. Results of the MCC on the sub-topic Measurement of the Amount of Substances.

Item	Weighted Mean	Description	Standard Deviation
a) how to determine the atomic mass of			
1. elements	4.53	Comprehensive	0.72
2. compounds	4.53	Comprehensive	0.72
b) the relationship of atomic mass to			
1. formula mass	4.30	In-depth	0.75
2. molecular mass	4.36	In-depth	0.76
3. molar mass	4.36	In-depth	0.70
c) how to solve for			
1. formula mass	4.43	In-depth	0.77
2. molecular mass	4.40	In-depth	0.83
3. molar mass	4.45	Comprehensive	0.75
d) the difference between and among molar quantities (formula mass, molecular mass, molar mass)	3.98	In-depth	0.87

51.06% of the students had displayed correct conceptions with regard to the significance of molar mass in measuring the amount of substances. Majority of the responses in the reflection log described how molar mass makes it easier to quantify the amount of substances. More so, students were able to realize that the molar mass makes measurement or counting of the amount of substances easier. Some students even manifested ideas that molar mass is equal to atomic mass. With these, students were able to relate the significance of molar mass in understanding better formulas of given substances.

Only a small percentage of students (27.66%) had displayed correct conceptions on the sub-topic, Determining the Formula of Substances. It can be noted that there is variety in the way conceptions were framed by the students. For example, Student 6 related formula mass to the definition of empirical formula. The same concise nature of conception can also be seen in Student 11's reflection log entry. On the other hand, Student 12 displays a more elaborate understanding of the topic evident in her inclusion of an example. Despite this, there were still a good number of students who had naive conceptions such as pertaining to formula and molecular masses as the same as empirical and molecular formulas.

As reflected in the IRF charts, students had naive initial ideas on how the amount of substances is measured. Examples of these naive ideas are "using instruments such as scale, spoons, etc.". However, it must be noted that some initial ideas included the terms AMU (atomic mass unit), using the mole concept, and using formulas. Towards the end, it can be observed that the refined ideas of students included some degree of correctness such as using different kinds of formulas, using N_A or Avogadro's number, using molecular, formula and molar mass and AMU. At the end of the lesson, the final ideas that surfaced from the student responses in the IRF charts have shown similarities with the initial ideas (i.e. AMU). However, the final ideas were more enriched and definitive of correct conceptual understanding. This suggests that students may have been already aware of the concepts to some degree but the extent to which the concept was introduced or encountered may be insufficient to result to enduring understanding.

6.4 Students' Conceptions on Determining the Formula of Substances

As seen in Table 5, the item on solving for percent composition of elements in a given compound had been rated with the highest weighted mean of 4.53. This suggests that students perceive their understanding as Comprehensive as opposed to the other two items. The item that concerns how molecular formulas of compounds are determined had the lowest weighted mean of 3.72. However, it must be noted the same item has the highest standard deviation of 1.21. This suggests that the students' responses were more spread out compared to the other items.

Table 5. Results of the MCC on the sub-topic Determining the Formula of Substances.

Item	Weighted Mean	Description	Standard Deviation
a) how to solve for the percent composition of elements in a given compound	4.53	Comprehensive	0.75
b) how to determine the empirical formula of compounds	4.06	In-depth	0.84
c) how to determine the molecular formula of compounds	3.72	In-depth	1.21

82.98% of the students had correct conceptions on the application of percentage composition in real life. Common responses include computation of grades, nutrition facts in food items, computation of body mass index (BMI), sales commission, interest rates, and tax computations. From among the different items in the reflection log, it must be noted that the item on applications of percentage composition had the highest frequency of correct responses and variation in the responses.

It is noteworthy that the item on the difference between empirical and molecular formulas had the least frequency of correct responses as opposed to the other items in the reflection log. There were only 21.28% of students who had correct conceptions pertinent to the difference of empirical and molecular formulas. This may suggest unclear or naive conceptions of the students. Most of the students this item blank while those who had correct conceptions such as Students 2, 7, and 10 appear to have a 'bookish' conception evident in the way the reflection entries were phrased and explained.

As seen in the Initial Ideas of the students in the IRF charts, students perceive the formula of substances to atoms/atomic mass and not the substance as a whole entity as evidenced by the highest frequency garnered by the '*depending on the substances involved*' idea. Though, it could be noted that there is a shift in perception as reflected by the Revised and Final Ideas of the students pertaining to computations of mass of different substances as prerequisite to determining the formula of give substances. More strikingly, the students were able to elicit key terminologies/concepts such as percentage composition, empirical formula, and molecular formula which got the highest frequency in the Refined Ideas, as means by which formula of substances can determined. Based on the discussion of the results above, it could be said that students have very good conceptions of percentage composition. This is evident in the way the students state a variety of applications of the principle of percentage composition in real-life (i.e. grade computation, sales, taxes, etc.). This is consistent with the Final Ideas of the students in the IRF chart. The students were able to correctly describe percentage composition as a means of determining the formulas of substances. On the other hand, as depicted in the student responses in the IRF chart, students have recognized the use of the empirical and molecular formulas which got the highest frequency in the Final Ideas, as means of determining the formula of substances. Although, it is salient that this

notion is rather simplistic as evidenced by the responses of the students in the reflection logs. The students have shown difficulty in differentiating empirical and molecular formulas.

The data gathered suggests that students have conceptual understanding of the Mole Concept. This is evident in weighted mean rating of the MCC, IRF charts, and reflection logs. This indicates that the use of the STS approach in teaching have a strong associated with the improvement and/or refinement of students' prior ideas. As seen in the implementing teacher's daily journal entry below, students may have associated the concept of mole to things they encounter in their daily lives.

"An analogy was given in explaining the mole: 1 box of cans of sardines would be compared to 1 mole, and the number of cans of sardines inside the box (10) was compared to the number of atoms in one mole (6.02×10^{23}). The class showed understanding when asked [questions]. They answered in unison and grasped the concept as expected".

The implementing teacher's use of analogy may be contributory to the students' exploration of other similar concepts that could be best associated with the concept of mole. The students also manifested a good grasp of the concept of the Avogadro's number - 6.02×10^{23} . Students were able to display correct conceptions in the reflection logs and IRF charts. Furthermore, students were able to show positive refinement of ideas in the way students perceive the Avogadro's number as used in measuring the amount of substances after being exposed to instruction using the STS approach. This has a strong association to Campbell's (2008) finding that learning ultimately begins with the known (initial) and proceeds to the unknown. Connecting everyday experiences with classroom topics and intentionally engaging preexisting knowledge with new classroom content [as being the characteristic of STS] can promote meaningful and lasting learning. Students were able to elicit the importance of counting and measuring the amount of particles. More so, the students displayed evidence of being able to apply this understanding in varied contexts.

Students frequently mistake the macroscopic level of representation of substances (such as molar mass) to that of microscopic levels of atoms and molecules (Furio, 2000). It may be evident in the data gathered from the MCT and MCC that some students still have prevailing misconceptions pertinent to molar mass. These students equate molar mass and atomic mass - that is the numerical value of molar mass is equal to the atomic mass. On the other hand, there is good number of students who had correct conceptions on how the molar mass is instrumental in better quantification of the amount of substances as seen in the IRF charts and reflection logs. This may suggest a positive association between improvement in students' conceptions and the use of STS approach in the classroom. It could be noted that the implementing teacher wrote in the daily journal,

"I used the analogy, a lion's pride... [in explaining the concept]. The number of lions [molar mass] can be described by the individual masses of the lions [representing the mass]."

Comparing molar mass to such an example could elicit student engagement, as problems drawn from real life situations engage the science students in scientific explorations (Smitha, & Aruna, n.d.). In addition, a similar study by Üce (2009) utilized a conceptual change process in teaching the mole concept. In chemistry, this process replaces chemical concepts with relevant concepts and improves the understanding of the learned concepts. Conceptual change among the students may have been facilitated by the replacement of the chemical concept [molar mass] of a relevant/familiar concept [lion's pride]. The same finding was asserted by Schank and Kozma (2002) such that an environment that engages students to build representations of a phenomena [or concept] leads to better understanding. It could be said that students' conceptions improve when they are given opportunities to construct their own representations.

It must be noted that students have naïve understanding of formula and molecular mass. Students often have mistaken these two for empirical and molecular formulas. Similarly, students also had misconceptions on the later [empirical and molecular formulas]. It could be said that the students used these two sets of concept interchangeably. This finding could be attributed to the lack of active involvement of the students in the discussion of these concepts. This is evident in the implementing teacher's journal entry.

"I reviewed them on the definition of formula and molecular mass... gave them a seatwork... more on mechanically solving."

Since the students were not given ample opportunities to apply their learning to new contexts, it could have led to poor concept retention and building. The use of multiple representations in combination can support a more complete understanding of a phenomenon (Kozma, Russell, Jones, Marx, & Davis, 1996). Thus, it could be said that learning such concepts such as formula and molecular mass [empirical and molecular formulas] needs more than just giving of seat works or problem sets for students to solve.

Students' conceptions on how formula of substances are determined can be viewed as not as well-developed compared to the other two subtopics (mole concept and Measurement of the Amount of Substances). The data gathered display that majority of the students were not able to properly define what empirical and molecular formula is [in the reflection logs] though they were able to identify it as the means in determining the formula of substances [in the IRF charts]. The students exhibit only knowledge, which is the lowest level in the Bloom's taxonomy of cognitive domains (Dahsah, et.al., 2008; Huitt, 2011). Thus, it could be said that students may have a recall of the key concepts but fail to translate it into something that makes sense. This can be attributed to the lack of instructional time allotment for this subtopic. It could be gleaned from the implementing teacher's journal entry below that the discussion of the subtopic was not well emphasized.

"The last lesson was [rushed] not given much emphasis... I gave them an example of a compound whose chemical formula was unknown... Molecular formulas was not [well] discussed because of time constraint."

As suggested by Koedinger, Corbett, and Perfetti (2010), the process of *sense-making* requires robust learning strategies that engage students into higher-order thinking independently from instruction. However, it can be said that sense-making processes include explicit comprehension strategies (Graesser, McNamara, & VanLehn, 2005) and explicit hypothesizing and scientific discovery processes (Klahr & Dunbar, 1988) and explicit argumentation such that in collaborative discourse (Asterhan & Schwarz, 2009). A good example of this was investigated by Nassif and Czerwinski (2014) when they investigated on the use of paper clips to teach empirical and molecular formula.

Overall, the students have shown improvement in conceptions about the mole concept with respect to the three subtopics – the mole concept, Measurement of the Amount of Substances, and determining the formula of substances. The subtopic on the Mole Concept was very well understood as evident in students' responses in the MCT, MCC, IRF charts, and reflection logs. Conversely, the subtopic on determining the formula of substances was least understood by the students. This is consistent with the results obtained from the analyses of the MCT and MCC vis-à-vis the responses in the reflection logs and IRF charts. With these, it could be said that the use of the STS approach in teaching may improve student conceptions pertinent to the topic of the mole concept.

7. Conclusion and Future Recommendation

Most of the students had correct pre-conceptions about the topic on the Mole Concept. However, some misconceptions were identified. These misconceptions were more particularly evident in the

subtopics of Measurement of the Amount of Substances and determining the formula of substances. Overall, STS approach was effective in improving students' conceptions based on the students' gain in scores in the post-test. The high student ratings of perceived student understanding suggest that STS approach can facilitate improvement student conceptions on the mole concept. The results of the t-test, the students' responses in the MCC, and the responses of the students in their IRF charts and reflection logs were consistent in reporting significant improvement in the students' conceptions on the Mole Concept.

Recognizing the limitations of this study, it is recommended that further studies look into the comparison of student achievement pertinent to a control and an experimental group. Also, a further study on the comparison of the students' conceptions with other variable such attitude, learning style, etc. is recommended.

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