Exploring Students' Conceptions on Stoichiometry Using SCQS and VCQS

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Abstract - *This study describes the prevalent conceptions held by third year high school students (n=204) on stoichiometry enrolled in one National High School in the Philippines. The Visual Conceptual Questionnaire in Stoichiometry (VCQS) and Symbolic Conceptual Questionnaire in Stoichiometry (SCQS) were used as the main instruments utilized in the study, which has a reliability coefficient of 0.66 and 0.65, respectively. Analysis of the conceptual test using VCQS and SCQS showed that biggest number of the students (57.11% & 59.07%) has incomplete understanding of balancing chemical equations. This implies that students did not fully understand the concepts on stoichiometry. Comparing students' performance on both the VCQS and SCQS, results revealed that there is significant difference on the performance of the students in the two tests. This indicates that students performed better in SCQS than VCQS. The findings of this study have potential in translating research insights into practical advice for teachers regarding tactical moves on how to diagnose students' conceptions on stoichiometry. This can also help the teacher to decide on what way/ways to be employed in teaching stoichiometry considering the use of particulate drawing and symbolic notation.*

Keywords: *Students Conception, Symbolic Conceptual, Visual Conceptual*

INTRODUCTION

Learning is an active process, and what students do with facts and ideas with which they have been presented depends to a very high degree on what they already think and believe. Horton [1] stated that being able to recognize and work with these student-held ideas and conceptions is thus a key component of an effective educational strategy.

Chemistry is a world filled with interesting phenomenon, appealing experimental activities, and fruitful knowledge for understanding the natural and manufactured worlds. However, it is so complex. Chiu [2] revealed that the students do not only understand the symbols, terminologies, and theories used in learning chemical concepts, but they also need to transform instructional language or materials that teachers use in the chemistry classroom into meaningful representations. She added that although many studies have been conducted in the area of misconceptions (otherwise known as "alternative conceptions" or "student conceptions") in chemistry, few studies exist those systematically collected students' conceptions of their understanding of chemical concepts. It is supported by Tan [3] that many researchers agree that the most significant things that students bring to class are their conceptions. Students' conceptions are often inconsistent with the science conceptions they are expected to learn.

Arasasingham [4] revealed that learning chemistry requires conceptualization and visualization skills as well as mathematical and problem solving skills. One of these is stoichiometry. There are many reasons behind this: one is that stoichiometry is an abstract topic and second the chemical vocabulary associated with solving stoichiometric problems seems to prevent students from applying their mathematical skills to chemical phenomena.

In 1988, Packer as cited by Camarote [5] described students difficulties with stoichiometry and stressed that 'a lack of understanding of the principles of measurement like what a quantity is, what a unit is and the relationship between them, is a root of students' problems with stoichiometry. His findings also showed that students could not even differentiate atom from a molecule.

Huddle and Pillay [6] conducted an in-depth study of Misconceptions in Stoichiometry among South

African chemistry I students. They gave one stoichiometric problem which asked the students to balance the equation, determine the amount of each reactant and to determine the limiting reagent for the reaction. The study revealed that students could not determine the 'limiting reagent' in a given problem, when one substance is added in excess.

This study would be of great help to the students and teachers who are directly involved in classroom learning especially, as well as the school administrators, curriculum planner, with mainly comprises the academe.

So, it is on the above-cited grounds that this venture on exploring the students' conception on stoichiometry using the VCQS and SCQS.

OBJECTIVES OF THE STUDY

The main objective of this study was to explore students' conceptions on stoichiometry of third year high school students using the Visual and Symbolic Conceptual Questionnaires on Stoichiometry. Specifically, it aims to:

1. describe the prevalent conceptions held by third year high school students on stoichiometry measured by the Visual Conceptual Questionnaire in Stoichiometry (VCQS) and the Symbolic Conceptual Questionnaire in Stoichiometry (SCQS); and
2. analyze the significant difference between the students' performance on the Visual Conceptual Questionnaires in Stoichiometry (VCQS) and the Symbolic Conceptual Questionnaire Stoichiometry (SCQS).

METHOD

This study employed the descriptive method which is a purposive process of gathering, analyzing, and interpreting data about prevailing or current conditions, practices, beliefs, processes, and trends. In particular, this study explores the students' conceptions on stochiometry using the VCQS and SCQS.

Population sampling was used in selecting the subjects of the study. There were all 204 third year high school students who took chemistry subject involved in this study in one National High School in the Philippines. The data gathered shall be treated confidentially and the respondents' answers dealt with utmost confidence and will not in any way affect their performance as student of the school.

To gather pertinent data on students' conception in stoichiometry for the study, two instruments were employed.

First, the researcher used the Visual Conceptual Questionnaire in Stoichiometry (VCQS) developed by the Batch 2007 Dep-Ed Tan Yan Kee Scholars which is a two tier, 10 item multiple choice format wherein the first tier of the instrument presents four multiple choice options in particulate drawings with an added second tier which is essentially an open ended segment that requires the students to explain the thinking or idea behind their choice. The contents of the instrument are balancing equations and excess and limiting reagents.

The second instrument used was the Symbolic Conceptual Questionnaire in Stoichiometry (SCQS) developed by the Batch 2008 Dep-Ed Tan Yan Kee Scholars. The SCQS was patterned from the VCQS wherein it is also a two tier, 10 – item multiple choice format but the choices are not based on particulate drawings but instead using the symbols and formulas of elements and compounds. It was followed by a second tier which is essentially an open ended segment that requires students to explain their thinking or idea behind their choice. This instrument was validated by three chemistry experts at De La Salle University, Manila, in terms of its face and content. A final draft was made and the pilot test was conducted at Tondo National High School, Manila. The result of the test was analyzed using KR-20. The results revealed that the reliability value is 0.65.

The following are the research procedure used in this study: Adapting the VCQS used as one of the research instruments of the study; Constructing the SCQS in accordance with the contents of the VCQS; Validating the SCQS to 3 science experts in terms of the content & pilot testing the instrument; Revising the SCQS for final copy; Asking permission to Schools Division Superintendent in conducting the study; Administering the VCQS & SCQS; Encoding, analyzing and categorizing students' explanations in the second tier of VCQS & SCQS; and Processing the data using the Statistical Package for the Social Sciences for the Personal Computer (SPSS-PC+).

For the purpose of classifying the responses of the students to both the VCQS and SCQS with ease and simplicity, the researcher modified the scheme which was based on work of Calik, Ayas and Coll as used by Camarote [5] as shown in Table 1. The tier questions in each instrument need such data analyses categories because the responses for the first tier questions comprise the knowledge domain, whereas the second tier relates to understanding.

Table 1. Categorization Scheme to Analyze Students Response

Code	Category	Description
CC/CR	Correct Choice with Correct Response	Correct option with responses that included all the components of the validated response
CC/AC	Correct Choice with Alternative Conception	Correct option but with responses that included at least one component of the validated response.
CC/INR	Correct Choice with Irrelevant/No Reason	Correct option but with incorrect response
IC/AC	Incorrect Choice with Alternative Conception	Incorrect option with responses that included at least one component of the validated responses
IC/INR	Incorrect Choice with Irrelevant/No Reason	Incorrect option but incorrect response

This was done by first encoding all the students' responses in the second tier for both the VCQS and SCQS. Then proportional statements with the same thought emerged together. After which their responses were categorized based on the above cited categorization scheme.

Descriptive statistics such as frequency, percentage and mean determined to describe students' performance and conceptual knowledge in stoichiometry. A histogram of students' score distribution presented for better presentation. The t-test: Paired Two Sample for Means was used to test the significant difference of the students' performance using the VCQS and SCQS.

RESULTS AND DISCUSSION

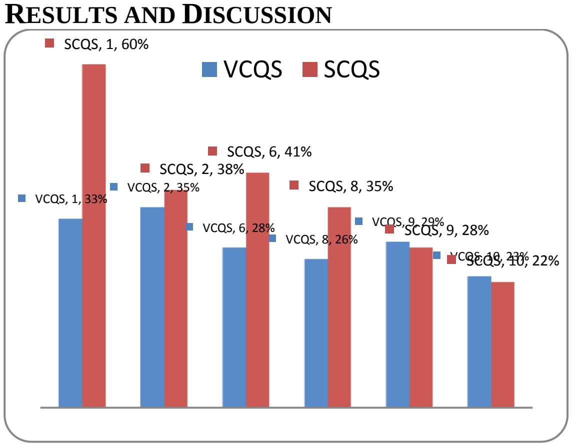


Figure 1. Percentage Distribution of Students' Correct Response in the First Tier of VCQS and SCQS in Balancing Chemical Equation

Percentage Distribution of Students' Correct Response in the First Tier of VCQS and SCQS in Balancing Chemical Equation

It can be seen in the Figure 1 that students got the high correct answer in SCQS for the items 1, 2, 6, and 8 compare to VCQS. But for the item 9 and 10, VCQS is higher than SCQS, with a difference of 1 percent only. The results revealed that students can get the correct answer through symbolic representation. They had difficulties in visual representations. It is supported in the study of Arasassingham et al. (2005). Their results revealed that the overall thinking patterns of students were from symbolic representations, to numerical problem solving, to visualization. The acquisition of visualization skills came later in the students' knowledge structure. Students had difficulties visualizing at a molecular or particulate level and making connections among the different representations. This implies that students had difficulties to answer the questions in visual representations rather than symbolic representations. It's because they used to discuss in class the Balancing Chemical Equation through symbolic representations.

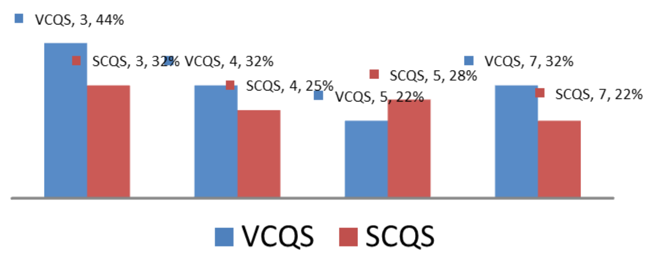


Figure 2. Percentage Distributions of Students' Correct Response in the First Tier of VCQS and SCQS in Excess and Limiting Reagent

Percentage Distribution of Students' Correct Response in the First Tier of VCQS and SCQS in Excess and Limiting Reagents

It appears in Figure 2 that VCQS is higher than SCQS for the items 3, 4, and 7. While for item 5, SCQS is higher compare to VCQS.

Table 2 presents the number and percentage of students who provided a reason for their choices in each item. It can be seen from this table that majority (61.76% - 73.53%) of the students in VCQS chose the wrong option with irrelevant/no reason for all the items as well as in SCQS except for item 1. Only few (0% - 2.94%) of the students in VCQS, and 0% - 2.45% in SCQS got the correct choice with correct reason

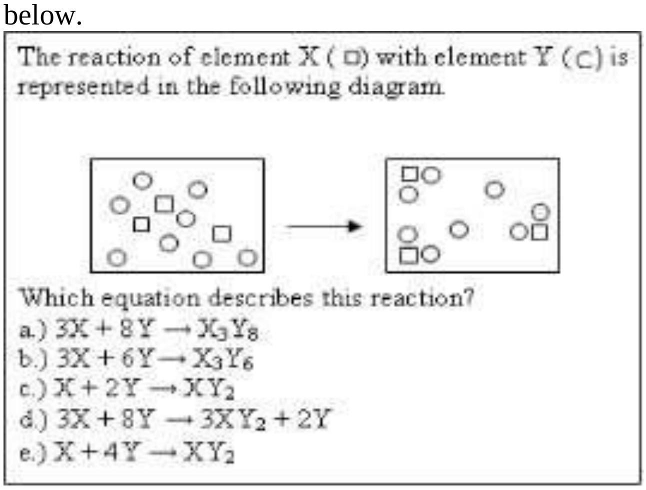
Table 2. Percentage Distribution of Students' Responses in the Second Tier under each category of VCQS and SCQS in Balancing Chemical Equation

Item No.	CC/CR	CC/AC	CC/INR	IC/AC	IC/INR
1	2.94	3.43	26.47	2.94	64.22
	2.45	1.96	55.88	0.98	38.73
2	1.96	1.47	31.37	3.43	61.76
	0.49	3.43	34.31	1.47	60.29
6	1.96	2.94	23.53	0.98	70.59
	0.49	1.47	37.75	3.92	56.37
8	0.00	0.49	25.49	0.49	73.53
	0.00	1.96	33.33	1.96	62.75
9	0.00	1.96	27.45	1.96	68.63
	0.00	0.00	28.43	0.98	70.59
10	0.00	1.47	21.57	3.92	73.04
	0.00	1.96	20.10	1.47	76.47

Note:
CC/CR = Correct Choice with Correct Response
CC/AC=Correct Choice with Alternative Conception
CC /INR= Correct Choice with Irrelevant/No Reason
IC/AC=Incorrect Choice with Alternative Conception
IC/INR= Incorrect Choice with Irrelevant/No Reason
VCQS -Numbers written in black color
SCQS – Numbers written in red color

In addition, most of the students did not provide reasons to their answers. Students had no respond in correct choice with correct reason category for items 8, 9, & 10. This indicates that students did not fully understand the stocihiometry specifically in terms of balancing chemical equation.

This finding is supported by the study of Nurrenbern and Pickering [9] demonstrated that chemistry students who can solve mathematical problems often have more difficulty answering particulate-level conceptual problems covering the topic stoichiometry. A sample question used by Nurrenbern and Pickering [9] is shown in Figure below.



The same question was used by Sanger (2005) in his study on evaluating students' conceptual understanding of balanced equations and stoichiometric ratios but he modified the questions by replacing X with Carbon and Y with Sulfur plus additional questions to assess students' abilities to properly perform stoichiometric calculations regardless of whether they provided a correct balanced equation. Results showed that the most common balanced equation used by students was $3C + 8S \rightarrow 3CS_2 + 2S$, where students left excess sulfur atoms in the equation. The study also demonstrated that most students showed confusion between the concepts of subscripts and coefficients (i.e. writing "C3" instead of "3C" for three independent carbon atoms, etc). On top of this, 64% out of 156 students used the stoichiometric ratio directly from their incorrectly balanced equation, demonstrating that even though they can use balanced equation in a stoichiometric algorithm correctly, they do not understand the chemistry concepts that a balanced equation is trying to convey.

Table 3. Percentage Distribution of Students' Responses in the Second Tier under each category of VCQS and SCQS in Excess and Limiting Reagents

Item No.	CC/CR	CC/AC	CC/INR	IC/AC	IC/INR
3	0.00	0.98	42.65	0.98	55.39
	0.00	1.47	30.39	1.47	66.67
4	0.00	5.39	26.47	0.49	67.65
	0.00	5.39	40.20	1.96	52.45
5	0.00	1.47	20.10	0.98	77.45
	0.00	0.49	27.94	0.98	70.59
7	0.00	2.94	28.92	0.49	67.65
	0.00	2.94	18.63	1.96	76.47

Note:
CC/CR = Correct Choice with Correct Response
CC/AC=Correct Choice with Alternative Conception
CC /INR= Correct Choice with Irrelevant/No Reason
IC/AC=Incorrect Choice with Alternative Conception
IC/INR= Incorrect Choice with Irrelevant/No Reason
VCQS -Numbers written in black color
SCQS – Numbers written in red color

It can be seen from Table 3 the percentage distribution of students' responses in the second tier under each category of VCQS and SCQS in Excess and Limiting Reagents. The results were the same as in Table 4 that most (55.39% - 67.65%) of the students in VCQS got the incorrect choice with irrelevant reason, while in SCQS, 52.45% - 76.47% of the students belong to this category. Nobody got the correct choice with correct reason. This implies that students had also no fully understanding in stochiometry specifically in Excess and Limiting

Reagents. This finding is supported by the study of Camarote [5] which states that provided substantial evidence that third year and fourth year science class students of one High School in the Philippines hold varied scientifically acceptable and alternative conceptions on stoichiometry particularly on two concepts-balancing chemical equations and excess and limiting reagents. More so, it also showed that 32.3% and 19.7% of the students manifested complete understanding in balancing chemical equations and excess and limiting reagents respectively in terms of percentage students who got correct choice and correct reason.

Furthermore, Wood and Breyfogle [10] as cited by Camarote [5] conducted a study entitled 'Interactive demonstrations for mole ratios and limiting reagents'. In this study, a conceptual-change, interactive lecture demonstrations on stoichiometry were 17 employed to 29 high school chemistry students to address their misconception on the said topic. A multiple-choice question format plus a separate open response questions were used to assess whether the use of interactive lecture demonstrations was effective. These tests were administered to the students before and after instruction. One of the questions included in the free-response assessment is shown in figure 6 which is all about mole ratios and limiting reagents. The most frequent incorrect answer was a representation that showed 2 carbon dioxide and 3 water molecules (55% pre and 31.0% post). This answer indicates that the students simply drew the products of the reaction without concern for how much of each reactant they started with. A group of responses showed some misconceptions related to mole ratios or coefficients in a balanced equation. These students would group several molecules into one group instead of drawing them as separate entities. There were also students who would correctly draw molecules; however, they did not draw products in the correct ratio. Following instruction the number of students showing misconceptions in both of these areas has decreased (24.1% pre and 10.3% post).

Students' Conceptions on Stoichiometry

Figure 3 presents the percentage distribution of students' conception conceptions of third year high school students in RNCHS using VCQS and SCQS. However, based on the result of the study, it shows that majority of the students had no explanation in both VCQS and SCQS. This implies that most of the students had no conception in balancing chemical equation and excess and limiting reagents.

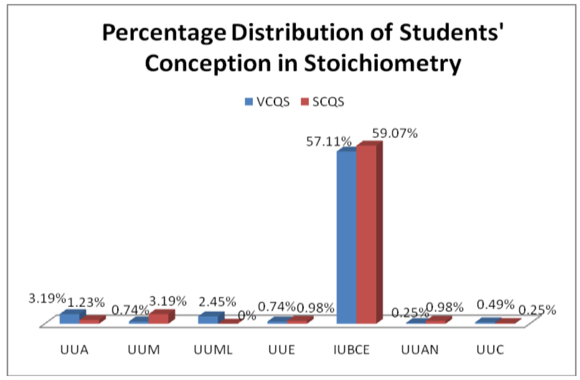


Figure 3. Percentage Distribution of Students' Conception in Stoichiometry

Testing for Significant Difference on Students' Performance in VCQS and SCQS

Table 4 presents the significant difference between students' performance in VCQS and SCQS. The results reveals that the computed t-value in Balancing Chemical Equation is -3.63 which lies in the rejection region while the computed t-value in Excess and Limiting Reagents lies in accepted region which is 0.17. But in the over-all mean, it reveals the result of the t-test: Paired Two Sample for Means used to test the hypothesis that there is no significant difference between the students' performance on the VCQS and the SCQS. The calculated t-value at 0.05 levels lies in the rejection region which is -3.65. So the decision is to reject the null hypothesis and conclude that there is a significant difference between the students' performance on VCQS and SCQS. The result further shows that students performed better on SCQS than VCQS. Mean average in VCQS is 3.03 while SCQS is 3.52. The result is supported by the study of Nurrenbern and Pickering [9] used particulate pictures to create conceptual questions in a study carried out among freshmen to compare conceptual questions and traditional (algorithmic questions). Their research argued that teaching students to solve problems about chemistry is not equivalent to teaching them about the nature of matter. Students can solve problems about gases without knowing anything much about the nature of a gas, and they can solve limiting reagent problems without understanding the nature of chemical change. Particulate pictures as conceptual questions were used in other research studies to distinguish between conceptual thinkers and algorithmic problem-solvers among students in tertiary education (Nakhleh, 1993; Zoller et al., 1995). Gabel et al., (1987) investigated the views of prospective elementary teachers of the particulate nature of matter. The test showed pictures of matter with atoms and molecules symbolized by circles and shading. They found out that even after the study of chemistry, students could not distinguish between some fundamental concepts such as solids, liquids, and gases, or elements, mixtures, and compounds in terms of particulate model.

Table 4. Table of Significant Difference between Students' Performance in VCQS and SCQS

Concepts	VCQS Mean	SCQS Mean
Balancing Chemical Equation *	1.74	2.25
Excess and Limiting Reagents **	1.29	1.27
Over-all Mean ***	3.03	3.52

t-computed * = -3.63
t-computed ** = 0.17
t-computed *** = -3.65
n = 204
t-tabular = ±1.97

CONCLUSION

This study revealed that few of the students had alternative conceptions on Stoichiometry specifically in balance chemical equation and excess and limiting reagent using the VCQS and SCQS. And Only few of the students had a scientific accurate conception on Stoichiometry . Majority of the students had no prevalent conceptions on this. This implies that they do not understand the chemistry concepts that a balanced equation is trying to convey as well as the excess limiting reagents.

Prevalent conception held by the students was on incomplete understanding of balancing chemical equations. Results of t-test for significant difference showed that students performed better in SCQS compare to VCQS. Students performed better in symbolic representations than in visual representations.

The results revealed that the overall thinking patterns of students were from symbolic representations, to numerical problem solving, to visualization. The acquisition of visualization skills came later in the students' knowledge structure. Students had difficulties visualizing at a molecular or particulate level and making connections among the different representations. This implies that students had difficulties to answer the questions in visual representations rather than symbolic representations. It's because they used to discuss in class the Balancing Chemical Equation through symbolic representations.

RECOMMENDATION

Accounts of students' conception on stoichiometry should serve as indicators for chemistry teachers regarding which concepts and processes pose the greatest challenge to learners. In this case, chemistry teachers must make sure that the learners have a good foundation on chemistry concepts specifically in balancing chemical equation, and excess and limiting reagents. Assessment of chemistry teachers must be observed.

A Two-Tier Multiple Choice Test is a type of exam that is very useful to assess performance of the students. In addition, multiple choice tests are more readily administered and scored than the other methods, and thus are particularly useful for classroom teachers. But this type of test is so very difficult to construct.

Teachers must have enough knowledge in constructing the multiple choice type of test. Since students performed better in SCQS than the VCQS, chemistry teachers might introduce their lesson using the particulate drawings so that students will become familiar and expose to the three representations used in chemistry- macroscopic, sub-microscopic/ particulate and symbolic. Pedagogical Plans and Innovation on Teaching Stoichiometry can also be developed based on the list of alternative conceptions provided in this study.

Analysis revealed that students performed better in stoichiometry using symbolic notation and less in particulate drawing, teachers can strengthen their students on visual representation by exposing them to problems that will require their visual intelligence. In this way, students will also learn to appreciate the significance of visual representations as they conceptualize theoretical entities of chemistry and science, as a whole.

Since education is a continuous process, chemistry teachers must continually upgrade themselves so that learning process in chemistry concepts can be developed. Teachers can't be taught of what they do not have. In this case, teachers must attend trainings regarding chemistry concepts and they must have to enroll in short-term courses thus they have a depth knowledge in teaching chemistry concepts.

There must be a follow-up study about the students' conceptions on stoichiometry using the

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VCQS and SCQS including the classroom observation.

Researchers in the field of education are encouraged to conduct the same study but different in setting. This is suggested for constant research in education leads to the better implementation of the curriculum in the country.

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