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CONCEPTUAL UNDERSTANDING IN SOLVING STOICHIOMETRIC PROBLEMS IN CLASS X CHEMISTRY

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ABSTRACT

This study examined the level of conceptual understanding in solving stoichiometric problems in class X chemistry under Trashigang District, Bhutan. In particular, this study examines the perceptions of teachers and students about conceptual understanding and algorithmic skills in stoichiometry. In addition, the study also examined the impeding factors in conceptual understanding and the relationship between students' ability to solve stoichiometric problems using conceptual understanding and algorithmic skills. The study employed a convergent parallel mixed methods design, which allows the collection of quantitative and qualitative data simultaneously. The target population comprised two hundred fifteen students and three chemistry teachers from three secondary schools. The research tools included a Stoichiometry Achievement Test for students and semi-structured interviews for teachers and students. Despite a strong positive correlation between conceptual understanding and algorithmic skills in solving stoichiometric problems, 71.16% of students showed higher algorithmic skills with lower conceptual understanding in the achievement test, suggesting that conceptual understanding was low in solving stoichiometric problems.

Keywords:
Algorithmic skills, Conceptual understanding, Impeding factors, Perception, Solving problems, Stoichiometry, Stoichiometric problems

1. INTRODUCTION

In 2008, the Ministry of Education, in collaboration with Royal Education Council (REC), conducted a standardized test in 18 schools in three subjects: English, Mathematics & Science. The results were that the student could not perform basic numeracy tasks, made simple mistakes in question-related to procedural applications, and performed poorly in question-related to word form problems, indicating that children lacked comprehension abilities (MoE, 2014).

Many students view chemistry as one of the most challenging and complicated subjects (Chiu, 2001; Gulacar, 2007) as it demands students to remember chemical symbols, equations, and scientific measurements. Such concepts made chemistry more abstract and often confined to chemistry classes, making chemistry students more troubled to learn chemistry (Gulacar, 2007; Treagust&Chittleborough, 2001).

Ali (2012), Gulacar (2007), and Lausin (2019) pointed out that stoichiometry is one of the most complex topics in chemistry. Stoichiometry is a branch of chemistry that calculates the number of substances involved in chemical changes or reactions (Lausin, 2019). Stoichiometry requires a range of skills, organized knowledge of chemistry, mathematical knowledge (Gulacar, 2007; Lausin, 2019), and students' good ability to understand the subject's basic concepts (Ali, 2012).

Science educators need effective methods and techniques for the students to become conceptual learners and successful problem solvers who can apply basic fundamental scientific principles to various phenomena and solve complex problems encountered in everyday situations (Ali, 2012; Gulacar, 2007). According to Gulacar (2007), learners solve problems better if they learn to organize their knowledge more effectively and meaningfully. Problem-solving occurs through the application and interpretation of conceptual knowledge. Conceptual understanding means that the person does not focus on words, symbols, or formulas but sees meaning and the ideas or intentions behind the problem. Problem-solving, on the other hand, fills the gap between what is given and what needs to be figured out. Solving problems requires the use of multiple tools and methods. Conceptual understanding is the most important factor contributing to effective problem-solving (Gulacar, 2007).

According to the study by Chiu (2001), in Taiwanese high schools, she found that high school chemistry students are more comfortable solving problems, strictly relying on algorithmic techniques rather than reasoning skills. There is a close relationship between the conceptual representation of declarative knowledge and problem-solving skills. It also enables them to have a better conceptual understanding, recognize meaningful patterns, and quickly conceptualize problems in depth. Bhutan Council for School Examinations and Assessment (BCSEA) (2019) highlights that REC/BCSEA/schools should prioritize learning in-depth instead of learning a broader breadth of the concept. Thus, removing superficial learning, incomplete understanding of concepts, and limiting students' ability to transfer and apply knowledge to unfamiliar contexts. Also, science teachers should stress more on deep conceptual understanding of the science curriculum and the instructions.

It is not surprising to observe students' low performance in chemistry examinations in Bhutan. Anecdotal evidence suggests that students struggle with stoichiometry concepts and conceptual understanding of the concepts lies behind algorithmic problem-solving. Students have been asked to solve most stoichiometric questions algorithmically in the Bhutan Certificate of Secondary Education (BCSE) chemistry paper. Few conceptual questions were asked based on the level of remembering. From the researcher's experience teaching class X chemistry for the last eight years, the researcher has seen students doing well in an algorithmic part of stoichiometric problem solving but could not give appropriate reasons for the problem. Class X chemistry learning in Bhutan includes physical chemistry, such as the mole concepts and stoichiometry, metallurgy, halogens, transition elements, and chemical energies. About 26% of the syllabus that students undertake is stoichiometry. A thorough grasp of mathematical background and conceptual understanding is required to develop proficiency in the chapter.

Similar research on conceptual understanding in solving the stoichiometric problem has been conducted in various countries. However, there is no literature available on conceptual understanding and algorithmic skills in stoichiometry in Bhutan. Therefore, this study investigated whether class X students of Trashigang District, Bhutan, are more conceptual thinkers or algorithmic problem-solvers in efficiently solving the stoichiometric problem. It also assessed the impeding factors affecting conceptual understanding in solving stoichiometric problems and evaluate teachers' and students' perceptions of using conceptual understanding and algorithmic skills in solving stoichiometric problems.

2. RESEARCH QUESTIONS

Main Question: To what extent does the student use conceptual understanding in solving stoichiometric problems in middle secondary schools?

Sub-questions:

1. What is the relationship between students' ability to solve stoichiometric problems using conceptual understanding and algorithmic skills?
2. What are the impeding factors contributing to students' conceptual understanding in solving stoichiometric problems?
3. What are teachers' and students' perceptions on the use of conceptual understanding and algorithmic skills in solving stoichiometric problems?

3. LITERATURE REVIEW

In science, chemistry plays a central position, and it provides fundamental concepts for understanding complex chemical reactions (Etokeren et al., 2019; Okanlawon, 2008).

Knowledge of chemistry is applied in medicine, engineering, and related courses and is utilized in industries to produce numerous products for the benefit of man and technological development (Etokeren et al., 2019). In the evolution of chemistry, stoichiometry played a vital role (Evans et al., 2006; Padilla &Garritz, 2012) and was viewed as a fundamental tool in the chemical toolbox (Evans et al., 2006). Stoichiometry is the most basic, central, and abstract topic in chemistry, which is essential for understanding quantitative and qualitative aspects of chemical reactions (BouJaoude&Barakat, 2003; Cardellini, 2012; Gulacar, 2007; Lausin 2019; Mandina&Ochonogor, 2017; Padilla &Garritz, 2012; Schmidt &Jignéus, 2003). And stoichiometry gave the worst result (Marais &Combrinck, 2009).

Many students developed algorithmic problem-solving techniques yet never understood the scientific concepts behind them (Robinson, 2003), which is very much needed (Ali, 2012). When a student tries to approach a stoichiometric problem algorithmically, they have a hard time understanding the problem and try to solve it for the sake of getting answers (Dahsah&Coll, 2007b; Gulacar, 2007). On the other hand, students who use the conceptual approaches know the relation between the calculation and the concepts. Using conceptual understanding improves students' ability to draw the connections between the concepts needed to solve the problems and rather than memorization (Gulacar, 2007).

3.1 Stoichiometry

The term stoichiometryis derived from the Greek words, *stoicheion*meaning "element" and *metron*meaning "to measure" (Kolb, 1978; Goldberg, 2015; Lausin, 2019). Although the translation from Greek to English seems to indicate the involvement and measurement of chemical elements only, chemical compounds are often involved and measured in chemical reactions (Lausin, 2019). According to Gauchon and Méheut (2007), Kaundjwa (2015), Lausin (2019), and Wilbraham et al. (2017),stoichiometry is the branch of chemistry that studies the quantitative relationships between reactants and products in a given chemical reaction based on the laws of definite proportions, conservation of mass and energy. Further, Bridges (2015), Hill et al. (2005), and Silberberg (2006) define stoichiometry as the study of the quantitative aspect of mass-mole number relationship, chemical formulae, and reactions which involve mole concepts and balancing of chemical equations.

Stoichiometry requires mathematical ability (Gulacar et al., 2013; Lausin&Kijai, 2020; Okanlawon, 2008) and organized knowledge of chemistry (Gulacar et al., 2013). Further, Evans et al. (2006) stressed that if one is skilful in solving stoichiometric problems, one will easily solve complex chemistry topics. In chemistry, both teachers and students find stoichiometry to be one of the most challenging topics (Bridges, 2015; Seetso&Taiwo, 2005;

Shadreck&Enunuwe, 2018), complicated and unmotivating (Fach et al., 2007; Schmidt &Jignéus, 2003) and one that student fear and apprehension (Bridges, 2015). Since teaching stoichiometric calculations is a difficult task (Schmidt, 1990), new instructional approaches and methodologies should be explicitly implemented in stoichiometry to prepare meaningful learners in chemistry. There is a need for adequate and correct conceptual understanding to solve stoichiometric problems successfully (BouJaoude&Barakat, 2003; Etokeren et al., 2019).

3.2 Conceptual Understanding Versus Algorithmic in Solving Problems in Chemistry

Researchers like Arasasingham et al. (2005), Ault (2001), DeMeo (2005), DeToma (1994), Gupta (2019), Kolb (1978), and Padilla and Garritz (2012) study focused on the algorithmic process, where students should solve stoichiometric exercises correctly and memorize some constant values like Avogadro’s number or molar volume.Nyachwaya et al. (2014) suggested that the reason for preferring algorithmic learning by a student is that they consider and see chemistry to be a collection of facts and formulas that they can memorize and use in examinations, resulting in no motivation to seek a deeper understanding of the subject. However, Cardellini (2014), Niaz and Robinson (1992), and Zoller (2002) concluded that training students in algorithmic-mode problems did not guarantee a successful understanding of conceptual problems as algorithmic and conceptual problems may require different cognitive abilities.

According to de Jong and Ferguson-Hessler (1996), Gulacar (2007), and Jonassen (2009), conceptual understanding of the facts, concepts, and principles is the most significant one among many in successful problem-solving. It supports problem solvers to bridge the schema or conditions represented with procedural or action memory producing satisfactory results. Having sound conceptual knowledge allows students to swiftly identify meaningful patterns and conceptualize problems at a deep level (Chiu, 2001; Harrison &Treagust, 2000). It also enhances implementing, linking, and formulating the existing concepts to a new concept (American Chemical Society [ACS], 2012; Chiu, 2001; Dahsah&Coll, 2007b; Sangguro et al., 2019; She, 2004). For instance, if a child uses conceptual knowledge to solve a familiar problem and during unfamiliar issues, he starts making new connections among his knowledge pieces, resulting in better conceptual development and organizing knowledge (Gulacar, 2007). According to BouJaoude and Barakat (2003), Chandrasegaran et al. (2009), Gabel (1999), Gulacar et al. (2013), Haider and Naqabi (2008), Hanson (2016), Kamariah and Daniel (2017), Mandina and Ochonogor (2017), Mansoor and Montes (2012), Piquette and Heikkinen (2005), Sanger (2005), and Sunyono et al. (2015), students apply algorithms without a significant conceptual understanding of the concept and struggle to solve problems in chemistry. Therefore, conceptual understanding is a basic need in the problem-solving of chemistry (de Jong & Ferguson-Hessler, 1996; Ouasri, 2017). However, conceptual understanding does not ensure correct solutions to the problem as some students who are good at a conceptual understanding of the concepts cannot solve problems (Nakhleh, 1993). Finally, the right combination of procedural knowledge and conceptual understanding is essential for solving stoichiometric problems successfully (Gerace, 2001; Gulacar, 2007; Gunbatar&Kalender, 2010).

3.3 Factors Affecting Conceptual Understanding of Stoichiometric Problems

According to Ali (2012), contextual factors such as teaching and learning, meaning imparted by teachers, schools, parents, and society, influence science's in-depth education. Therefore, recognizing the impediments that hinder the learning process and encouraging teachers and schools with social working conditions can boost academic performance, if not lead to failure (Ali, 2012). Some of these factors include;

3.3.1 Curriculum Factors

The chemistry curriculum for secondary classes contains a wide range of concepts relating to organic, inorganic, and physical chemistry that a child should learn and master in two years (Ali, 2012). The nature of the curriculum provides limited opportunities for students to practice scientific skills and encourages students to take up rote memorizing of the facts and ignore conceptual understanding. Also, mostly the curriculum is exam orientated (Dahsha&Coll, 2007a).

Although the teaching of stoichiometry generally aims to achieve two goals: developing students' conceptual understanding of the concepts and their ability to solve numerical problems, the type of content and the standard for understanding the topic may differ (Furio et al., 2002; Gulacar, 2007). Ali (2012) states, "It becomes evident that there exists a gap which becomes increasingly wider between curricular demand and the cognitive levels of middle school students" (p.3). Similarly, Cracolice et al. (2008), Marais and Combrinck (2009), Neville et al. (2018), and Stefani and Tsaparlis (2009) felt it could be due to concepts being abstract, complex, challenging, and when students cannot keep up the pace of a lesson and get good marks. In addition, Bennett (2008) and Pappa and Tsaparlis (2011) felt this scenario was worsened by the traditional forms of assessment in chemistry, which tend to be algorithmic and focus on students' ability to get the correct answer. Nyachwaya et al. (2014) support the claim that most of the assessments in chemistry tend to focus more on students' ability to recall definitions and facts, apply known formulas and algorithms to solve problems, and less on conceptual understanding. Therefore, the curriculum must nurture the achievement of 21st-century skills such as innovation, creativity, enterprise, and universal human values. A dynamic learning culture, creative teaching-learning pedagogies, and valid learning assessment will allow students to develop higher-order (conceptual) cognitive skills (MoE, 2014).

3.3.2 School Factors

According to Ali (2012), the complexity of classroom life is vital for effective learning as teachers and students. Teachers and students collaborate in various discussions, communicate ideas and debates producing common understanding, generate new knowledge, help students take accountability for their learning, and drive in-depth understanding of essential science ideas and practices. On the contrary, the students' challenges get captured more inclusively due to the complexity of the classroom social environment during routine teaching.

3.3.3 Teachers Factor

According to Ayoade (2012), Bridges (2015), Etokeren et al. (2019), Gayeta and Caballes (2017), Lausin and Kijai (2020), MoE (2014), and Pushkin (1998), a teacher plays a vital role in promoting students' understanding of stoichiometry. A teacher should be creative and resourceful in presenting concepts of stoichiometry, addressing students' difficulties, and enhancing students' learning. Similarly, Andayani et al. (2018) reported that to address the challenges of the 21st century quality of teachers should be improved.

In Thailand, chemistry teachers focus more on training students to solve numerical problems preparing for the examination and pursue little understanding of the concepts making students good at the algorithmic knowledge of chemical concepts than a conceptual understanding of a given concept (Dahsah&Coll, 2007a). Similarly, Ali (2012) found a massive gap between the Pakistan national chemistry curriculum and the classroom practice, where students learn chemistry. The teacher-centered and rote-memorization approach allows teachers to dispense knowledge strictly based on textbooks. Thus, contributing little to accomplishing the conceptual content knowledge, skills, and attitudes in learning chemistry.

According to BouJaoude and Barakat (2000), Sawrey (1990), and Treagust and Chittleborough (2015), teachers find it easier to teach algorithms and formulas, neglecting conceptual knowledge. The teacher assumes that the students who produce the correct numerical answer understand the underlying concepts(Dahsah&Coll, 2007b; Nakhleh, 1993; Nakhleh& Mitchell, 1993; Nyachwaya et al., 2014; Puskin, 1998). Thus, chemistry teachers opt for algorithmic questions in their assessments (tests and exams) over the conceptual explanation of numerical problems (Gulacar, 2007).

It is recommended that chemistry teachers facilitate student development of logical reasoning skills through cognitive enrichment experiences in chemistry courses (Bird, 2010; Wu & Shah, 2003). The teachers need to adapt the curriculum by adjusting instruction strategies, and materials, and designing activities to the level of students' cognitions and experiences to involve students in process-based learning and increase their confidence and competence in science at the secondary level (Ali, 2012). Additionally, chemistry teachers should emphasize conceptual knowledge in solving problems, bridging a gap between abstract and algorithmic problem-solving skills and student success. That way, science students can create a better conceptual understanding, and non-science students can participate more actively and begin to understand the nature of science (Gulacar, 2007). Therefore, science teachers need to emphasize more in-depth conceptual and epistemic knowledge of the science curriculum, its mode of instruction, and child-centered teaching and assessment approaches (BCSEA, 2019).

3.3.4 Students Factor

The Program for International Student Assessment-D (PISA-D) analysis report points out that the Bhutanese students find difficulties in those items, which requires them to form a broad understanding and interpretation of the text, reflecting and evaluating the content. The finding also points out that the Bhutanese students perform well in those items that require lower cognitive skills, causing more significant performance gaps in more demanding tasks (BCSEA, 2019). In addition, Ali (2012) also found that when a student gets into class IX & X secondary science curriculum, especially for chemistry, without sound knowledge of the subject, the student's inability to establish a good understanding of basic concepts of the subject has hindrance in learning. Similarly, Chiu (2001) stated that the students facing difficulty using their conceptual knowledge to solve a problem are not due to a lack of knowledge but may be due to limited knowledge of the content that inhibits transferring to the problem.

Concepts of chemistry are more abstract and interlinked with previous knowledge and are often limited to the classroom (Ali, 2012; Gulacar, 2007). The learner needs the conceptual understanding to link several concepts, and some students can connect their knowledge pieces to execute complex calculations (Gulacar, 2007). However, many science students use more algorithmic than rationalization leading to memorizing its details, such as meaning and applications, only to reproduce the tests (Gulacar, 2007; Harrison &Treagust,

2000; Marais &Combrinck, 2009). Also, the lack of conceptual scientific knowledge, procedural mathematical skills, and language skills in understanding the given problem are crucial factors to successful results (Marais &Combrinck, 2009).

The intervention, such as stimulating students' motivation to learn and engage in deep and insightful thinking, addresses the massive gap between students' conceptual understanding of the basic concept and the in-depth learning of chemistry in advance (Ali, 2012; Treagust&Chittleborough, 2015). Gulacar (2007), Robinson (2003), and Treagust and Chittleborough(2015) therefore recommended three levels of studying chemistry as shown in Fig. 2.1 to develop conceptual understanding and avoid rote memorization.

3.4 Perceptions on Conceptual Understanding and Algorithmic Skills in Stoichiometry

Ali (2012), in his study, interviewed the teacher, and the teacher pointed out that to enhance the student's more profound understanding of a concept teacher should go for in-depth and breadth teaching of the concept. Students have to spend lots of time and effort memorizing accurate information from textbooks such as definitions, laws, theories, principles, chemical equations, and many more, only to reproduce in the examination. Another teacher expressed that students have a moderately complex structure of ideas and experiences and need proper guidance and motivation to help gain a deeper understanding between new knowledge and their pre-existing knowledge. Therefore, building a conceptual understanding was seen as very important (Ali, 2012).

Students feel that the concept of stoichiometry is the one-to-one ratio between moles to atomic mass units. The number of moles for a given substance is conserved in every reaction. There is a one-to-one ratio of reactants and the products in a chemical reaction, ignoring balancing a chemical equation (BouJaoude&Barakat, 2000; Dahsah&Coll, 2007a; Huddle &Pillay, 1996; Staver&Lumpe, 1993). Ali (2012), in his study, reveals that students' motivation in science learning is vital for promoting conceptual change and engaging students in deep and reflective thinking, which are the fundamental instruments to enhance students' achievement in science.

Lin et al. (1996) concluded that students are more interested in concepts than in algorithmic aspects of chemistry problem-solving. Similarly, in his study, Akinoso (2017) claimed a strong positive effect on students' attitudes to mathematics and performance in chemistry. A student who wishes to study chemistry must possess adequate knowledge of Mathematics.

4. METHODOLOGY

4.1 Research method

The study used convergent parallel mixed methods to collect the data. According to Johnson and Onwuegbuzie (2014), mixed methods research aims to reap from the strengths and minimize the weaknesses of a qualitative or quantitative method carried out in single research studies.

The qualitative approach addressed to determine the relationship between conceptual understanding and algorithmic skills, teachers' and students' perceptions, and the factors affecting students' conceptual understanding. Simultaneously, the quantitative method collected the data to address an in-depth understanding of students' conceptual understanding of stoichiometry. Thus, the triangulation of one set of findings with another enhanced interferences' validity.

4.2 Population and Sampling Techniques

This study used a purposive sampling technique for SAT as only class X students of three schools in TrashigangDzongkhag were selected. For semi-structured interview, purposive sampling was used in the selection of three chemistry teachers, amongst science teachers, and a simple random sampling was used for selecting six students from each school.

Teachers and students from three TrashigangDzongkhag middle schools participated in the study. All students (total of 215 students) from these three schools took the stoichiometric Achievement test, and six students and one teacher (currently teaching class X Chemistry) from each school participated in the semi-structured interview.

4.3 Research Instruments

4.3.1 Stoichiometry Achievement Test (SAT)

The test consisted of ten two-tier items. The test included some aspects of stoichiometry such as a) Balancing a chemical equation (Question 1 & 2), b) Percentage composition (Question 3 & 4), c) Empirical and molecular formula (Question 5 & 6), d) Gas laws (Question 7 & 8), and e) Molar concepts (Question 9 & 10). The researcher developed the test items by analyzing related literature and modified questions from the BCSE Chemistry Book for class X.

The first part of the item checked the student's algorithmic skills; each item had four possible multiple-choice answers, where the student had to solve the question and then select the correct answer from the given choices. The second part of the item checked students' conceptual understanding; each item had a reasoning part, and students had to provide a reason for or explain their choice of answer in the first part.

The students were asked to sit for the SAT for approximately one hour to complete the test. Students' responses for each item were marked as correct or incorrect. The students were considered good problem solvers if they answered the problem-solving part. Similarly, the student had a good conceptual understanding of the concept if they gave valid reasons.

Two-tiered conceptual questions are the best among many conceptual questions (Robinson &Nurrenbern, 2006) and increase understanding of how students consider a concept or a phenomenon during learning (Chiu, 2007). Chandrasegaran et al. (2009), Robinson and Nurrenbern (2006), and Nakhleh (1993) mentioned that the first tier of the items would consist of a multiple-choice content question that asked students what would happen in the first question (algorithmic question), while the second tier prompted a reasoning response (conceptual question).

4.3.2 Semi-Structured Interview

According to Denscombe (2014), the semi-structured interview does not firmly follow a formalized list of questions, and the interviewer can formulate questions that can probe the interviewee to give appropriate answers.

The semi-structured interview was administered to both teachers and students (focused group) to assess their perception of conceptual understanding and problem-solving abilities in stoichiometry and factors hindering their conceptual understanding of the concept. The researcher selected a teacher and six students from each school for the interview.

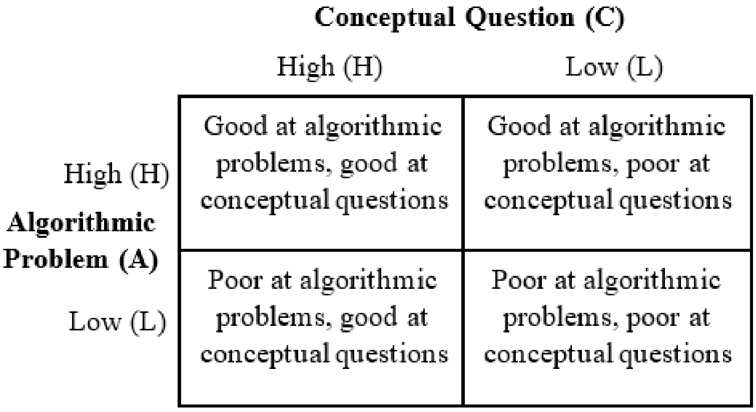
4.4 Data analysis

The qualitative data were analyzed using thematic content-based analysis, and the quantitative data were analyzed using Statistical Package for Social Sciences (SPSS 22) software. Data collected were triangulated to support each other. Ginyigazi (2018) and Neuman (2014) stated that triangulation tests the consistency of the findings obtained through different instruments.

The students were required to answer algometric questions and provide an argument for their answers. The researcher developed a scoring rubric to measure students' performance. For the short reasons given by the students, the scoring scheme had 1 (correct) or 0 (incorrect) points, and no partial scores were considered. Students were categorized based on the marks scored into a high problem solver, low problem solver, have high conceptual understanding, and have low conceptual understanding, as shown in Fig.4.1 on the extent of their performance. The coding scheme for this section was adapted from Chiu's study (2001). Students were assigned to one of the two groups in each category to evaluate and compare students' performance between algorithmic problems (coded A) and conceptual understanding questions (coded C). In each category, a student was categorized as a high performer (H) if a student's total score is 50% or more (5 points from 10 points, one point for each item) and categorized as a low performer (L) if a student scored 49% or less.

The codes were assigned based on the combination of students' performance on every paired question. All the possible combinations are shown in Fig.1. Correct answers on an algorithmic problem are coded as HA, and an incorrect answer on a conceptual question is coded as LC, as shown below;

HAHC: Algorithmic problem high achievement; conceptual question high achievement
LAHC: Algorithmic problem low achievement; conceptual question high achievement
HALC: Algorithmic problem high achievement; conceptual question low achievement
LALC: Algorithmic problem low achievement; conceptual question low achievement



		Conceptual Question (C)	
		High (H)	Low (L)
Algorithmic Problem (A)	High (H)	Good at algorithmic problems, good at conceptual questions	Good at algorithmic problems, poor at conceptual questions
	Low (L)	Poor at algorithmic problems, good at conceptual questions	Poor at algorithmic problems, poor at conceptual questions

Fig.1: categories of students and distributions in their performance

Note. Adopted from "Algorithmic problem solving and conceptual understanding of chemistry by students at a local high school in Taiwan," by M.H. Chiu, *Proceeding of the National Science Council*, 11(1), 2001, p.24.

5. RESULTS

Qualitative data were analyzed using coding, drawing the themes for the thematic analysis, and data filtering. The quantitative data were analyzed using Microsoft Excel 2019 and by running the normality test, correlation, independent t-test, and paired t-test in SPSS 22. The studies of data are presented in both narrative and tabular forms. In the narrative, certain parts of the interview dialogue are directly used. The interview participants are referred to using codes like Tr 1 – Tr 3 for teachers and Std 1 – Std 18 for students. The demographic details of the research participants are also presented.

5.1 Stoichiometry Achievement Test

This section dealt with the triangulation of data collected from interviews and achievement test scores, which pertained to research questions 1. *What is the relationship between students' ability to solve stoichiometric problems using conceptual understanding and algorithmic skills?*

Fig.2 shows students' performance during the stoichiometry achievement test for each algorithmic part and their corresponding conceptual understanding part. While students could answer most algorithmic questions correctly, they could not answer correctly in a conceptual understanding. Only a few could answer both algorithmic and conceptual questions correctly. The significant difference between the number of students able to answer the algorithmic part correctly and the conceptual understanding part indicated the students' ability to use conceptual understanding in solving stoichiometric problems in chemistry. For example, for item 1, one hundred seventy-one students answered correctly in the algorithmic part, and only eleven students answered correctly in the conceptual understanding part. In this example, it can be said that students are better at algorithmic problem-solving than the conceptual understanding of the concepts.

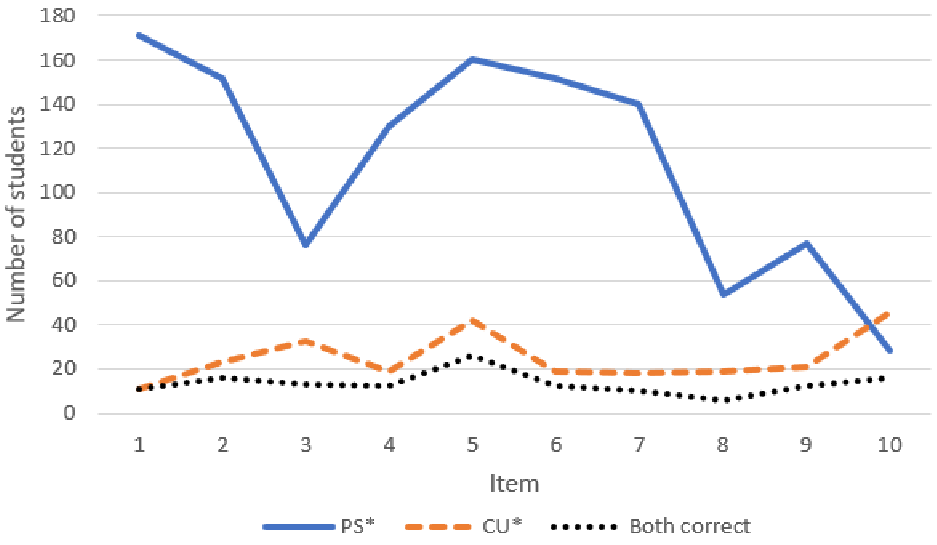


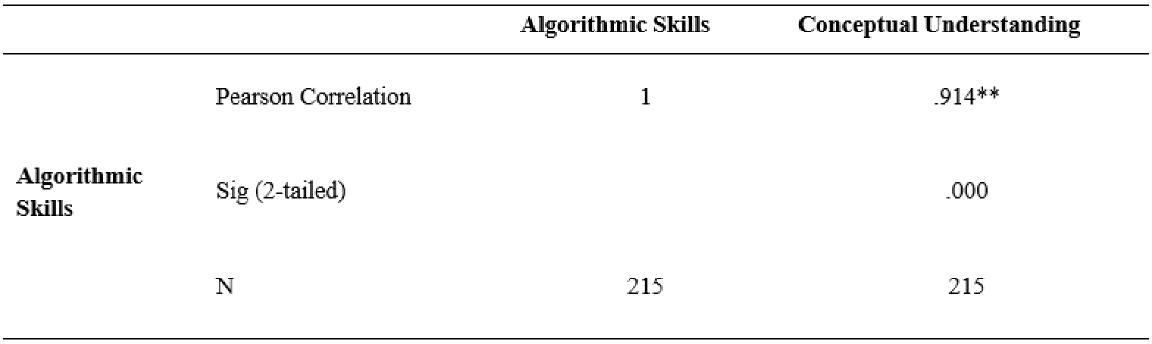
Fig.2: student's performance in stoichiometry achievement test

However, the above finding demanded the need to determine a statistically significant association. Therefore, some statistical tests (T-test and Correlation) were performed to determine the significant use of conceptual understanding in solving stoichiometric problems.

The parametric tests such as correlation and hypothesis tests (t-test) were performed. An independent t-test compared the scores of algorithmic skills and conceptual understanding in solving stoichiometric problems, and sample t-test compared the algorithmic skill and conceptual understanding in each category of items.

5.1.1 Pearson Correlation

Table 1: Correlation Between Problem-Solving and Conceptual Understanding (Pearson Correlation)



		Algorithmic Skills	Conceptual Understanding
Algorithmic Skills	Pearson Correlation	1	.914**
	Sig (2-tailed)		.000
	N	215	215

**. Correlation is significant at the 0.01 level (2-tailed)

The Pearson correlation test was performed at a 95% confidence interval to determine a relationship between conceptual understanding and algorithmic problem-solving skills. The Pearson correlation test revealed a perfect positive correlation between conceptual understanding and algorithmic skills ($p<0.01$, degree of correlation(r)$=0.914$). That meant that when students' conceptual understanding increased, their algorithmic skills also increased and vice versa.

Similarly, both teachers and students felt a strong relationship between conceptual understanding and algorithmic skills in learning stoichiometry. For instance, Tr 1 said;Students are facing challenges in understanding the stoichiometry concept clearly and face great difficulty in numerical fields also. They lack conceptual thinking because the majority of them fail to use the concept when they are solving the numerical questions related the stoichiometry. They face difficulty in problem-solving because most of the students do not understand the clear-cut information on stoichiometry.

Tr 3 said, "Students with better conceptual understanding, in general, are good problem solvers. It is through the understanding of concepts that students can apply for solving problems". Similarly, Std 4 felt that if one of them were missing, then both were missing. Std 4 explained as follows;Conceptual understanding will help us understand the essence of the question, and algorithmic skills will help us solve the problem. If one of them is missing, then both are missing.

5.3.2 T-test

Knowing that there was a strong relationship between conceptual understanding and algorithmic skills, the researchers wanted to find out to what extent students used conceptual understanding and algorithmic skills in solving stoichiometric problems. Thus, an independent t-test and paired sample t-test were performed to test the assumed hypothesis in both cases.

5.3.2.1 Independent t-test.

H_0 = There is no difference in the use of algorithmic skills and conceptual understanding in solving stoichiometric problems

H_A = There is a difference in the use of algorithmic skills and conceptual understanding in solving stoichiometric problems

Table 2: Comparison of Algorithmic Skills and Conceptual Understanding (Independent t-test)

	Grouping	**Mean**	**Mean difference**	**Sig (2-tailed)**
Scores	Algorithmic skills	5.30	4.14	.000
	Conceptual understanding	1.16		

Table 2 reveals that the test was significant ($p<0.01$). Therefore, the null hypothesis was rejected, as the calculated significant value was less than 0.05. There was enough evidence to support that there are differences in the use of algorithmic skills and conceptual understanding in solving stoichiometric problems by the students.

5.3.2.2 Paired Sample t-test.

Similar to independent t-test, paired sample t-test was performed to test students' performance; conceptual understanding, and problem-solving in five categories of test items, as shown in Table 3. The assumed hypothesis was drawn as follows;

H_0 = There is no difference in the use of algorithmic skills and conceptual understanding in each category of stoichiometric problems by students

H_A = There is a difference in the use of algorithmic skills and conceptual understanding in each category of stoichiometric problems by students

Table 3: Comparison of Algorithmic Skills and Conceptual Understanding in Each Category of Stochiometric Problems (Paired Sample t-test)

	Category	**Mean**	**SD**	**Sig (2-tailed)**
Pair 1	AS* Chemical equation – CU** Chemical equation	1.344	.643	.000
Pair 2	AS* % composition – CU** % composition	.702	.458	.000
Pair 3	AS* Empirical & molecular formula – CU** Empirical & molecular formula	1.172	.598	.000
Pair 4	AS* Mole concepts – CU** Mole concepts	.744	.437	.000
Pair 5	AS* Gas laws – CU** Gas laws	.181	.410	.000

AS* scores in Algorithmic Skills CU** scores in Conceptual Understanding

The paired sample t-test (Table 3) reveals that the test was significant in all the five categories of test items ($p<0.01$). Therefore, the null hypothesis was rejected, as the calculated significant value was less than 0.01. There was enough evidence to support that there are differences in the use of algorithmic skills and conceptual understanding by students in each category of stoichiometric problems.

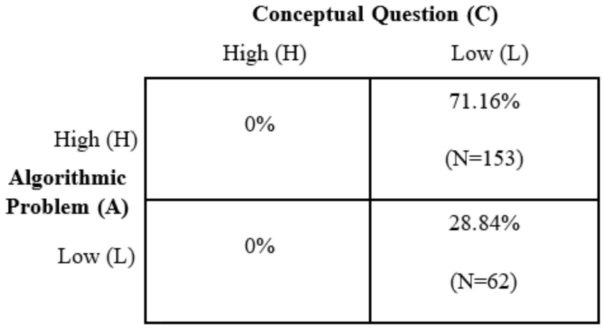
Since both independent t-test and paired sample t-test revealed differences in the usage of conceptual understanding and algorithmic skills in learning stoichiometry, there was a need to identify which category our students are good in. Chui's (2002) rubrics and table (see Fig.1) was used to categorize the student based on the marks scored in the stoichiometry achievement test as follows;

HAHC: Algorithmic problem high achievement; conceptual question high achievement

LAHC: Algorithmic problem low achievement; conceptual question high achievement

HALC: Algorithmic problem high achievement; conceptual question low achievement

LALC: Algorithmic problem low achievement; conceptual question low achievement



		Conceptual Question (C)	
		High (H)	Low (L)
Algorithmic Problem (A)	High (H)	0%	71.16% (N=153)
	Low (L)	0%	28.84% (N=62)

Fig.3: Categories of Students Based on Their performance in SAT

Fig. 3 points out that 71.16% (N=153) of the students fell in HALC, and the remaining 28.84% of students (N=62) fell in LALC category. That indicated that the majority of our students use more algorithmic skills than conceptual understanding in solving stoichiometric problems in class X chemistry. These findings also aligned with some students' preferences to use algorithmic skills rather than conceptual understanding. Std 1 said that he felt it easier to solve algorithmically because it was easier to use a formula. Further, he added that numerical problems are much easier to solve than giving conceptual answers. Similarly, Std 16 said;

I think I'm a little bit good at algorithmic problem-solving. Sometimes for critical thinking, questions are given in twists and turns and it is difficult to understand the question. But while solving a problem it is easier to substitute the numbers.

5.4 Interview

The interview was conducted in a focus group for students and a one-to-one interview with the chemistry teachers to garner students' and teachers' opinions about using conceptual understanding in solving stoichiometric problems and the factors affecting them. The reason to have interviews was to answer the first and second research questions; Question 2. *What are the impeding factors contributing to students' conceptual understanding in solving stoichiometric problems?* Question 3.*What are teachers' and students' perceptions of the use of conceptual understanding and algorithmic skills in solving stoichiometric problems?*

From the sample, eighteen students who voluntarily agreed to take part were interviewed. There were three focus groups, one each from a school, with six participants each (three male, three female) in a group. Three chemistry teachers, one each from a school too participated in the one-to-one interview. The conversation during the interview was audio-recorded, and the audio clips were transcribed and coded using Microsoft Office Word 2019. After coding, transcription, and data filtering, the following themes emerged, as listed below.

1. Factors contributing to the conceptual understanding of students in solving stoichiometric problems
2. Teachers' and students' perceptions on the use of conceptual understanding and problem-solving skills in solving stoichiometric problems

In the following paragraphs, teachers' and students' opinions are discussed based on each theme. The interviewees' names have been changed to hide their identity for ethical concern.

5.4.1 Factors Contributing to the Conceptual Understanding of Students in Solving Stoichiometric Problems

According to the teachers' and students' responses, the factors affecting the conceptual understanding of students in solving stoichiometric problems was as follows;

5.4.1.1 Curriculum

The abstract nature of the subject was one of the impeding factors for students to learn stoichiometry. For instance, Tr 1 stated, "Some stoichiometry concepts are abstract, so it isn't easy to understand by the students, and they do not pay interest in learning it." Tr 2, in addition, felt there was a gap in the practical use of the concepts learned. Thus, students are not able to make a connection and face problems in solving stoichiometric problems. Tr 2 stated;

> Due to the gap between the real feel of concept and textual knowledge, students' conceptual understanding and problem-solving skills have deteriorated.

Few teachers and students felt that, due to lots of theories and formulas, which has lesser applications in their actual situation were the impeding factor for them. Std 1 stated that due to more numerical problems, similar formulas, and the mass number of many atoms. It was making him more confused. Similarly, Std 6 stated that she feels formulas are similar in calculating an atomic number, volume, molecular formula, mass number, etc., making her more puzzled, and sometimes she gets a headache. Further, Std 14 stated;

I think it is all because of more theories and formulas in the chapter. I cannot remember all of them and get confused using the correct formula to the given question.

Some students felt the textbook used with different editions were also one of the factors. Std 9 stated that the challenge he faced was different editions of a textbook that different students had. As a result, different students solve different questions during the class activities, and they cannot discuss their solutions. The situation is more worst when they are given homework or an assignment.

Teachers also felt that some of the concepts of stoichiometry should be included in the class IX syllabus. Stoichiometry is introduced superficially as extended learning and is not included in the syllabus. They felt introducing the topic in class IX could reduce the burden in class X. Tr 2 stated;

Few stoichiometry concepts should be taught in class IX. Therefore, students will not be burdened with many new ideas, theories/laws, and formulas in class X. The concept is there but not included in the syllabus.

5.4.1.2 Teacher's Competency

Both teachers and students felt that the teacher's competencies, such as teaching skills, strategies, and motivation, are also major factors that impede the learning of stoichiometry. Most of the teaching is in lecture form, and the content is not elaborated well for understanding the concept. Tr 1 stated that teachers using inappropriate teaching skills and strategies to teach stoichiometry were another factor. The lecture method may not work every time; therefore, the teacher must change their teaching style accordingly to inspire and build students' interest in the subject. Further, Std 2 stated;

The teacher introduces the topic and gives us the formula to use. But he does not provide the definition and does not explain and elaborate. Therefore, I cannot understand the concept.

Students also feel that the pace of the teacher's lesson was fast for them to grab the information. The teacher was in a hurry to complete the content. The teacher often gave another question to solve before the given question was solved. Thus, the student lost interest, and the learning stoichiometry was lesser. Std 1 said that the teacher taught very fast because sometimes he went to the following question before completing the present work. He felt that it would be better if the teacher taught slightly slowly. Similarly, Std 3 explained that the teacher said that the content is very vast, taught very fast, and taught calculation part only. If a teacher could also teach them how to solve word problems, it would be easier to face such questions in the examination. Knowing the calculation but does not know the word problem is more confusing. Further, Std 10 stated;

When I'm doing the teacher's assigned activity, I try my best, but when I reach in between solving, the teacher jumps to another question, and I can't catch up. Therefore, I lose interest in between. (Laugh) When I go to the next question, I forgot the previous one that I did.

Teachers felt that using ICT, more activities, conducting experiments could be remedial for learning the concepts. Tr 1 said that the teacher had to use problem-solving pedagogical techniques to address the difficulty faced by students in problem-solving. Further, conducting experiments, showing relevant videos, and using simulations comprehend the concept more clearly. Tr 2 stated;

Teachers can help transform the textual and abstract knowledge into hands-on practices by using animation, video lessons, relevant software, and providing more problem practice can scaffold conceptual learning. Memorization of mass numbers and atomic numbers can be done to some extend by students.

Similarly, students felt that the teacher needed to use ICT, assign individual or group activities, and avoid using lecture methods to enhance their stoichiometry learning. Std 3 said that if a teacher gave them group work (presentation), different students would have different ideas, share their ideas, and solve the problem together. Therefore, they would understand more. Further, Std 17 said;

If the teacher goes on teaching without any presentation or writing on the chalkboard only, I think productive teaching and learning won't occur. If the teacher can give examples, use charts, or show YouTube videos, we can get or develop our thinking.

However, some students felt that brain-break, anecdotes, and extra classes could also be helping remedies. For instance, Std 16 stated that the teacher taught in a hurry during class, and questions were asked one after another. Often, they do not even get a break to recapitulate the lesson learned. Std 17 stated;

It would be better if the teacher could explain the concepts slowly during class time. If we cannot complete the lesson on time then maybe the teacher can take some extra classes. We cannot understand in a hurry, so we get lesser marks in the test and the exam.

5.4.1.3 Students' Competency

Teachers and students felt that students' language competencies affect stoichiometry learning. Tr 1 said, "Students' competency in the English language is poor. So, it is difficult for them to comprehend the questions and solve the numerical problems". Similarly, Std 13 felt the same and stated;

Due to a lack of good English language proficiency, many of the students, including myself, face lots of problems understanding what the teacher teaches and understanding the context of the content. In addition, lack of concentration in the class and lack of revision can be another barrier.

A mathematic calculation was an essential element in learning stoichiometry. It was found that students' mathematical competency was another impeding factor. Teachers felt that due to poor mathematical skills, understanding of stoichiometry concepts was hampered. Tr 3 said;

Due to poor mathematical skills, they also face problems in solving mathematical problems and understanding the concepts.

Due to the abstract nature of the content, and poor mathematical background, students opted to memorize laws, formulas, and calculation procedures. With memorizing, lots of confusion and lack of understanding was seen in the students. For instance, Std 14 said that he found the topic stoichiometry was more of mathematical calculations. Therefore, he memorized the formula but was not able to explain the concept. In addition, Tr 1 said;

A majority of students opt the rote learning. They memorize the concepts without fully understanding the meaning of concepts and terminology. I knew they were rote learning because most students cannot solve stoichiometry's analytical and critical questions. But they do pretty well in low-order thinking questions. So, I conclude the majority of the students are regurgitating the concepts through memorizing without fully understanding them.

However, some students did not memorize the concept but tried to understand the concept and avoid memorizing. Std 9 said, "I go for understanding the stoichiometry concept. Some of our friends are good at problem-solving, and I take their help. I visit the library for referring books and browse the internet. I try to understand the concept rather than memorizing the concept". Similarly, Std 11 said;

Instead of memorizing the concept, I try to make my own stories using my friends' names or sometimes as a processing process in the industries. For example, I know atomic numbers and mass numbers of the first thirty elements of the modern periodic table, calculating empirical and molecular formulas. Therefore, I can easily remember it in tests and examinations.

However, teachers felt that mentioning atomic numbers and mass numbers along with the question could ease students and refrain them from memorizing. Tr 2 said, "The need to memorize atomic masses by students was problematic. It can be given in the question to ease students' work".

5.4.2 Perception on Conceptual Understanding and Algorithmic Skills in Solving Stoichiometric Problems

Regarding the teachers' and students' perceptions of the importance of conceptual understanding and algorithmic in learning stoichiometry, there were mixed responses from teachers and students. Table 4 shows that 33.33% of teachers felt that algorithmic skills are more important, but 66.67% of teachers felt that both; conceptual understanding and algorithmic skills are essential in learning stoichiometry. On the other hand, 14.29% of students felt that conceptual understanding was more important, and 85.71% felt that both; conceptual understanding and algorithmic skills are essential in learning stoichiometry.

Table 4: Perceptions of Teachers and Students About the Importance of Problem-Solving Skills and Conceptual Understanding in the Learning of Stoichiometry

	Conceptual Understanding (%)	**Algorithmic Skills (%)**	**Both (%)**	**TOTAL**
Teachers	0	33.33	66.67	100
Students	14.29	0	85.71	100

Tr 2 said that algorithmic problem-solving were important in stoichiometry because stoichiometry involved more calculation work. It gave students a deeper understanding of the concept. Whereas some students felt conceptual understanding are more important than problem-solving. Std 1 said;

I feel the conceptual understanding of the concept is more important. If we know the concepts, then we can quickly and easily learn how to solve numerical problems.

However, the majority of teachers and students felt both; conceptual understanding and algorithmic skills are essential in learning stoichiometry. Tr 1 said;

Both conceptual understanding and algorithmic skills are important to understand the stoichiometry concepts completely. Without having a good concept of stoichiometry, we cannot understand its numerical questions. Most of the students don't understand the questions, which results in wrong findings. So, concepts are essential to get the correct finding from questions. At times, algorithmic skill is also essential. There are many calculations parts in stoichiometry. If we don't have good algorithmic skills, we will face challenges in calculation parts. So, both are important in learning stoichiometry.

Std 9 said, "In my opinion, I guess both are important. We have children with different abilities; some can quickly catch up with the concept, but some learn by solving problems mathematically. So, from my side, both are important". In addition, Std 15 felt that competency-based questions are the reason for the importance of both conceptual understanding and algorithmic skills as she said;

I would say both conceptual and algorithmic skills are essential. Nowadays, more competency-based questions are asked even for the calculation works. Conceptual understanding will help us understand the concepts of such questions, and algorithmic skills will help in calculation work. Therefore, both conceptual understanding and algorithmic skills are important in learning stoichiometry.

6. DISCUSSION

This chapter discusses key findings of the present study. The study's findings cover four major themes, and each theme was discussed in the following four sections in reference to the previous related studies. The first section discusses on the relationship between conceptual understanding and algorithmic skills in solving stoichiometric problems. Followed by the second section on the category of students based on their performance in achievement tests. The third section discusses the impeding factors for the use of conceptual understanding in solving stoichiometric problems. Finally, the fourth section discusses the findings on the perceptions of teachers and students on the use of conceptual understanding and algorithmic skills in solving stoichiometric problems.

6.1 Relationship between Conceptual Understanding and Algorithmic Skills in Solving Stoichiometric Problems

The Pearson correlation test of the stoichiometry achievement test showed a perfect positive correlation ($P<0.01$, $r=0.914$) between conceptual understanding and algorithmic skills in solving stoichiometric problems. This finding was supported by the teachers and students' responses who participated in the face-to-face interview. For example, one of the teachers said that due to a lack of conceptual understanding, students faced challenges in understanding the stoichiometry concept clearly and had difficulties solving stoichiometric problems. Similarly, another teacher shared that students who are better in conceptual understanding are good problem solvers because, through understanding concepts, they could easily apply them to solve problems. Further, one of the students shared that if either conceptual understanding or algorithmic skill are missing, both are missing. She explained that conceptual understanding helped them understand the question, and algorithmic skills helped them solve it.

These findings of the present study were in line with the findings of the similar study conducted in Taiwan with class X and XI students by Chiu (2001). The researcher reported that when students used algorithmic problems into pictorial representation in a microscopic way, they explored how one constructed internal models of chemical compounds. In addition, the researcher pointed out that according to the cognitive psychological viewpoint, there is a close relationship between conceptual understanding for reasoning skills and arithmetic skills for solving problems. Chiu's view was incongruent with Nicoll and Francisco (2001), who claimed that the student's ability to extract information strongly correlate to solving problems. Similarly, Cracolice et al. (2008), Gulacar (2007), Harmon (1993), and Staver and Lumpe (1995) claimed that inadequate understanding of the concept impeded the problem-solving abilities of a student. A study done by Adigwe (2012) with four hundred senior secondary school students on the effect of mathematical reasoning skills (conceptual understanding) and their achievement in stoichiometry found out that there was a drastic improvement in students' achievement in solving stoichiometric problems. This indicated presences of a strong correlation between conceptual understanding and algorithmic skills in solving a stoichiometric problem. Similar findings were also brought by Boujaoude et al. (2004) and Boujaoude and Barakat (2003), that students' ability to apply mathematics was the critical requirement to solve such problems.

However, these findings of the present study contradicted the findings of Salta and Tzougraki (2010) in Greece. The authors supported that there was no dependence between the conceptual understanding and algorithmic skills in solving the problems. For instance, their study found that students performed better in algorithmic questions even if they could not have an excellent conceptual understanding of the concepts. Similar findings were seen in Agung and Schwartz's (2007) work with Indonesian students. The study showed no positive correlation between students' performance in conceptual questions and algorithmic questions, suggested that students tend to use algorithmic skills without having a sound conceptual understanding of the chemistry concepts.

6.2 Category of Students Based on Their Performance in Achievement Tests

Both independent t-test ($P<0.01$) and paired sample t-test ($p<0.01$) statistically proved differences in the students' conceptual understanding and algorithmic skills in solving stoichiometric problems. Using the rubrics used by Chiu in his study (2001), 71.16% (n=153) of the students were categorized as HALC, and the remaining 28.84% (n=62) were classified as LALC (see Table 4.7). These findings indicated that most students tend to use algorithmic skills to solve problems associated with stoichiometry without having a conceptual understanding of the problems. Some of the students expressed that they felt it easier to solve the stoichiometric problem by substituting numbers and memorized formulas.

These findings were coherent with the findings of Nurrenbern and Pickering (1987). They found statistically significant differences ($P<0.05$) between conceptual understanding and algorithmic skills in solving stoichiometric problems. In their study, 85% of the students answered the algorithmic questions successfully, and only 49% answered the conceptual questions correctly. A similar pattern of a higher number of students answering algorithmic questions than the conceptual understanding questions was seen in various studies such as a study done by Bodner and Herron (2002), Boujaoude and Barakat (2003), Chiu (2007), Chiu (2001), Cracolice et al. (2008), Dahsah and Coll (2007a), Dahsah and Coll (2007b), Gultepe et al. (2013), Hanson (2016), Holme and Murphy (2011), Laswadi et al. (2016), Lausin (2019), Lausin and Kijai (2020), Mandina and Ochonogor (2017), Nakhleh et al. (1996), Salta and Tzougraki (2010), Sangguro et al. (2019), and many among other. The authors pointed out that the students could solve algorithmic questions without an adequate conceptual understanding of the concepts.

The researcher felt that this could be due to some impeding factors discussed in section 5.4.

6.3 Impeding Factors for the Use of Conceptual Understanding in Solving Stoichiometric Problems

The study's qualitative findings revealed three factors that impeded the use of conceptual understanding in solving stoichiometric problems in class X chemistry: 1) Curriculum content, 2) Teachers' competencies, and 3) Students' competencies.

6.3.1 Curriculum

This study revealed that teachers and students found the stoichiometry chapter was more abstract, and there was a gap between the concepts and the real-life applications. These findings correlated with the findings of Agogo and Onda (2014), Andayani et al. (2018), BouJaoude and Barakat (2003), Chiu (2001), Gayeta and Caballes (2017), Gulacar (2007), Hanson (2016), Mandina and Ochonogor (2017), Marais and Combrinck (2009), Sirhan (2007), Slatter (2018), and Uchegbu et al. (2016) stating stoichiometry had many abstract concepts. Similarly, Ali (2012), Andayani et al. (2018), BouJaoude and Barakat (2003), Cardellini (2012), Chiu (2001), Gayeta and Caballes (2017), Sirhan (2007), and Slatter (2018), stated that the facts and topics had limited applications in new situations. Therefore, making stoichiometry difficult for students to understand (Andayani et al., 2018). Further, these findings were parallel to the findings of Claesgens et al. (2002), stating,Instead, much of current chemistry instruction focuses on covering a breadth of topics without a consistent emphasis on integrating across concepts. For example, a typical high school chemistry course might group learning into a dozen or more separate concepts, such as stoichiometry, atoms and elements, the periodic table, chemical bonding, molecular structure, ideal and real gases, acid-base equilibrium, solubility, oxidation-reduction reactions, thermochemistry, chemical kinetics, and thermodynamics. Students are taught many discrete knowledge pieces without an emphasis on coordinating this knowledge into a functional whole. (p3)

Similarly, Sirhan (2007) claimed that if the concept was approached from several directions, it would enable the learner to grasp the key concepts and establish the meaningful links of concepts to a coherent whole. Further, Childs et al. (2012) reported that the Bhutanese science curriculum of class IX-XII are more academic and content-oriented with limited use of everyday life’s applications and examples. The curriculum should include more local examples, field trips, and projects.

6.3.2 Teacher’s Competency

According to the responses collected from both teachers and students who felt inappropriate teaching skills, strategies, and methods impeded students from understanding stoichiometric concepts. This finding of the study was coherent with Chiu (2007), who reported that inappropriate instructional strategies and styles resulted in lower conceptual understanding of the concepts. Similar findings were reported by Andayani et al. (2018), BouJaoude and Barakat (2000), Bridges (2015), Hoffman and McGuire (2010), Salta and Tzougraki (2010), and Uchegbu et al. (2016), stating how crucial was teaching strategies, skills, and methods in the teaching of stoichiometry.

The importance of infusing group work or cooperative learning to enhance the teaching and learning of stoichiometry was strongly felt by both teachers and students. Robinson and Niaz (1991) found that students taught with cooperative methods better understand stoichiometry than those led by lecture methods. These findings were congruent with the findings of Basili and Sanford (1991), Bodner and Herron (2002), Bridges (2015), Cardellini (2006), Danili and Reid (2006), Fielder (1996), Gabel (2003), MoE (2020), Moran and Keeley (2015), Reid & Yang (2002), Roth (1989), Tenaw (2015), Treagust and Chittleborough (2015), and Wood (2006).

Both teachers and students pointed out that the usage of analogies in stoichiometry enhanced students' conceptual understanding. It was coherent with the findings of Bodner and Herron (2002), Friedel et al. (1990), Gabel (2003), Gabel (1993), Staver and Lumpe (1993), Tenaw (2015), and Treagust and Chittleborough (2015) reported the significance of analogies in enhancing students conceptual understanding in learning stoichiometry.

ICT incorporated in teaching had drastically improved students conceptual understanding of stoichiometry (Bayram&Comek, 2009; Bridges, 2015; Fach& et al., 2007; Gabel, 2003; Kimberlin&Yezierski, 2016; Lausin&Kijai, 2020; Sanger, 2000; Sunyono et al., 2015; Tenaw, 2015; Treagust&Chittleborough, 2015; Wu & Shah, 2003).

6.3.3 Students' Competency

Due to poor language proficiency, students faced problems in learning stoichiometry and chemistry. This finding was coherent with the findings of Chiu (2007), Danilli and Reid (2006), Gabel (1999), Malcolm (2015), Marais and Combrinck (2009), and Treagust and Chittleborough (2015). They reported that students faced difficulties understanding familiar words used in everyday meaning to connect to the language of chemistry. For instance, Gabel (1999) stated that terms like strong had different meanings in ordinary words than chemistry. Similar findings were produced by Johnstone (2006) and Sirhan (2007), that such difficulties were seen more in those students whose second language was English.

The mathematical background of a student had an essential role in understanding stoichiometry. This finding was in parallel to the findings of Bridges (2015), Dahsah and Coll (2007a), Etokeren et al. (2019), Furio et al. (2002), Gabel et al. (1984), Marais and Combrinck (2009), Neville et al. (2018), Robinson (2003), Shadreck and Enunuwe (2017), and Wu and Shah (2003), who in their separated study reported that students with good mathematical background achieved good reasoning and solved stoichiometric problems algorithmically.

Rote memorization was pointed out as another challenge faced by the students. They had difficulties in memorizing and reproducing the content, thus had more confusion in learning stoichiometry. This finding was incoherent with Etokeren et al. (2019), who stated that students who opted for rote memorization of the concept had difficulties recalling information. Thus, they scored low on the stoichiometry test. Similar findings were drawn byBodner and Herron (2002), Bridges (2015), Cook et al. (2013), Heyworth (1999), Malcolm

(2015), Marais and Combrinck (2009), Robinson (2003), and Treagust and Chittleborough (2015), through their studies. However, BouJaoude et al. (2004), Roth (1989), and Sirhan (2007) stated that due to the problematic nature of the subject, students were encouraged to memorize the information and were able to score well in stoichiometry test. Still, the conceptual understanding of the concepts was missing in them.

6.4 Perceptions of Teachers and Students on the Use of Conceptual Understanding and Algorithmic Skills in Solving Stoichiometric Problems

The majority of teachers and students felts that both conceptual understanding and algorithmic skills are essential in learning stoichiometry. It was incoherent to the findings of Griffin and care (2015), who stated that conceptual understanding, arithmetical problem solving, and decision-making are essential 21st century skills. Similary ACS (2012), Gerace (2001), Gulacar (2007), Gunbater and Kalender (2010), Hanson (2016), Mandina and Ochonogor (2017), Nakhleh and Mitchell (1993), and Treagust and Chittleborough (2015), who in their separate studies mentioned that the right combination of conceptual understanding and algorithmic skills are essential in solving problems.Further, Andayani et al. (2018) stressed that the constructivism learning approach caters to blending conceptual understanding and algorithmic skills in learning science. Constructivism approaches helped students develop more profound thinking skills and provided scientific methods to solve the problem through students' involvement in real-life experiences.

7. CONCLUSION

The strong positive relationship ($p<0.01$, $r= 0.914$) between conceptual understanding and algorithmic skills in solving stoichiometric problems indicated that students could solve stoichiometric problems successfully using algorithmic skills if they had an excellent conceptual understanding of the concepts or vice-versa. However, there were significant differences in conceptual understanding and algorithmic skills in solving various stoichiometric problems. The majority of the students fell in the HALC category, which indicated that the students used more algorithmic skills than conceptual understanding in solving stoichiometric problems.

The study also revealed the impeding factor for the lower use of conceptual understanding in solving stoichiometric problems. For instance, firstly, the curriculum was vast, abstract in nature, and stressed more on algorithmic skills, making students unable to relate its relevance and practical application to their everyday lives. Secondly, besides the lecture method, teachers lacked various teaching strategies and skills such as group activities or cooperative learning, infusion of ICT, laboratory experiments, and analogies, making students lose interest in learning stoichiometry. Thirdly, students with poor language competencies and mathematical backgrounds faced great difficulties in learning stoichiometry. Thus, students opted to memorize the algorithmic procedure without a proper understanding of the concepts.

Further, the study found out mixed perceptions towards the use of conceptual understanding in learning stoichiometry. However, most of the teachers' and students' perceptions were positive towards conceptual understanding and algorithmic skills in solving stoichiometric problems. Thus, it indicated that conceptual understanding is equally important in solving stoichiometric problems in class X chemistry.

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We hereby declare that this work is completely original and all the authors of the referred articles are properly cited and are free of plagiarism.

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