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The Effects of Using Particulate Diagrams on AIMS Students' Conceptual Understanding of Stoichiometry

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ABSTRACT

The lack of conceptual understanding of stoichiometry among high school students is a valid concern not only because it impedes students' problem-solving ability in stoichiometry but also because it is a significant predictor of performance in college Chemistry. High school Chemistry teachers, therefore, should evaluate and update their classroom practices to best support conceptual learning, especially in the topic of Stoichiometry. This study investigates the effects of a visual-based pedagogical approach on the understanding of four concepts of stoichiometry, namely the concepts of representative particles, mole ratio, limiting reagent and theoretical yield among tenth-grade Chemistry students at AIMS, Saraburi, Thailand. The approach involves systematic and extensive use of particulate diagrams in the instruction of stoichiometry concepts in a real classroom setting. The study further examines the attitudes of the students towards the method. The study employed the one- group pre-test post-test design. A Conceptual Stoichiometry Test (CST), and an Attitude Towards the Use of Particle Diagrams (ATPD) questionnaire were the instruments used to collect data. Data were analyzed using the paired-sample t-test. Key results indicate that the approach had a significant and positive effect on the students' conceptual understanding of stoichiometry and that the students generally had a favorable attitude towards the use of the method.

Keywords: Stoichiometry, Conceptual Understanding, Particulate Diagrams.

INTRODUCTION

Stoichiometry problem-solving poses challenges to Chemistry high school students at the Adventist International Mission School. From the analysis of student responses to a variety of stoichiometric questions, their Chemistry teacher has identified that the primary source of these challenges is students' minimal or lack of conceptual understanding of Stoichiometry. AIMS students appear to have misconceptions regarding some Stoichiometry concepts, including the concept of mole, the concept of representative particles, stoichiometric ratio, and the concept of theoretical yield and limiting reagent. AIMS students' inadequate understanding of these concepts impedes their ability to solve stoichiometry problems successfully. Although studies have shown that the use of particle diagrams can effectively improve students' conceptual understanding of stoichiometry, this visual tool has not been applied systematically and extensively in Chemistry classes at AIMS, and its impact specifically on AIMS students' conceptual understanding of Stoichiometry has not been explored.

Purpose of the Study

The purpose of this study is to investigate the effects of using particle diagrams (also called particulate diagrams), on AIMS high school students' conceptual understanding of Stoichiometry, specifically on the concepts of representative particles, mole ratio, limiting reagent, and theoretical yield. In this study, a companion booklet entitled "Thinking the Particulate Way!" is designed and used as complementary material in lessons related to concepts of Stoichiometry. At the end of the series of lessons, its effects on students' conceptual understanding of Stoichiometry, and the students' attitudes towards its use in learning Stoichiometry is examined.

LITERATURE REVIEW

Stoichiometry

Stoichiometry is a branch in Chemistry that deals with the calculations of the quantities of substances involved in chemical changes or chemical reactions (Pearson, 2017). The word stoichiometry is derived from Greek words: *stoicheion* (meaning "element") and *metron* (meaning "to measure"). (reference) Though the translation from Greek to English seems to imply that only chemical elements are involved and measured, very often chemical compounds too are involved and measured in chemical reactions.

Stoichiometry calculations deal with the quantities of the chemical elements, or compounds present before undergoing a chemical change called the reactants, and the chemical elements or compounds produced after the chemical change called the products. These quantities are measured in terms of mass, volume, number of moles, and number of representative particles.

Both students and teachers find Stoichiometry to be one of the most challenging topics in Chemistry. Evaluation of senior secondary school Chemistry syllabus reported that students and teachers viewed the module on stoichiometry problematic (Adediran & Isaac, 2005). Even after alternative approaches for teaching stoichiometry were developed, students and teachers still regarded the topic as being complicated and unmotivating (Parchman, 2006). Interviews with high school chemistry instructors revealed responses that were overwhelmingly similar in that they found it challenging to teach stoichiometry (Bridges, 2015). They also reported that students' reactions toward learning about the concepts of stoichiometry were that of fear and apprehension (Bridges, 2015). Research authors also agree that stoichiometry concepts are challenging for students to grasp and therefore discouraging (Schmidt and Jignéus, 2003).

Dahsah and Coll (2007) reported that even after major national curriculum reforms, Thai grades 10 and 11 students who participated in a survey demonstrated less than the acceptable level of understanding of concepts related to stoichiometry. The Thai students' responses also suggested that they resorted to the use of algorithms with little knowledge of the underlying concepts. Findings from a study involving eight hundred sixty-seven grade 12 Indonesian students showed that in general, Indonesian students were more successful in answering questions that are algorithmically based, and that there were no strong positive correlations between student performance on conceptual questions and algorithmic questions (Agung, 2007). These studies suggest that students who have not sufficiently grasped the chemistry concepts behind a problem tend to use algorithmic methods by merely using a memorized formula, manipulate the equation and plug in numbers until they fit.

What makes stoichiometry so challenging to learn and to understand is that the macroscopic features of chemical reactions, on which stoichiometry is primarily based, are emergent properties resulting from actions at the atomic or molecular level (Chi, 2005; Chi & Roscoe, 2002; Penner, 2000). These submicroscopic actions operate at a non-human scale and are unable to be directly manipulated or experienced. Therefore, developing an intuition for connecting these macroscopic features with submicroscopic interactions is difficult (Yaron, Leinhardt, & Karabinos, 2004). Still another learning challenge is the mastery of the representational system of symbols, formulas, equations, and mathematical manipulations used to describe and explain these unseen submicroscopic interactions that give rise to the macroscopic features. Expert chemists move freely among these three levels as they pursue their work, including that of instruction (Johnstone, 2000). However, students, whose knowledge framework is rudimentary at best, have great difficulty understanding their teachers when explanations move away from the macroscopic level with which they have everyday experience. Effective stoichiometric instruction should promote student development of cognitive connections among the macroscopic, submicroscopic, and representational aspects of stoichiometry.

Bridges (2015) suggests that teachers need to be "knowledgeable, creative, and resourceful" in helping their students to learn stoichiometry. In recent years many alternative approaches for teaching this unit of Chemistry have been developed. In Germany, a set of stepped supporting tools (SST) was implemented to help grade 9 students working on Stoichiometric problems (Fach & Parchman, 2007). A study on 96 Indonesian students reported that macro–sub-micro–symbolic teaching which employs multiple representations could effectively enhance student mental models and understanding of chemical reaction which is the basis for solving stoichiometric problems (Sunyono, Yuanita & Ibrahim, 2015). Inquiry-based lessons using particulate level models produce statistically significant improvement in grades 11 and 12 students' conceptual understanding of stoichiometry even though there were variations in the intervention delivery (Kimberlin & Yezierski, 2016). An instructional model that incorporates definitions, computer-generated visuals at the submicroscopic level and physical samples of various substances at the macroscopic level seems to improve students' conceptions of pure substances and mixtures. (Sanger, 2000). These studies suggest that an understanding of the submicroscopic composition of chemical elements or/and compounds that make up the reacting and resulting substances in chemical reactions is an essential prerequisite to interpreting and solving stoichiometric problems.

These studies cited above concluded and recommended that a more visual pedagogical approach to teaching Stoichiometry could effectively advance student conceptual understanding of Stoichiometry. Consequently, the AP Chemistry curriculum was redesigned to include learning objectives that contain references to particulate representations of chemical phenomena (College Board, 2013). However, the shift in emphasis toward conceptual understanding using particulate images presents a real challenge for many Chemistry teachers because most of them have had limited exposure to particulate ideas before teaching Chemistry, including during their high school years. Therefore, translating the recommendations for using particulate representations into teaching practices can be a daunting task. The scarcity of classroom-ready lessons or supplementary materials based primarily on particulate descriptions, further compounds the challenge. From my own experience as a Chemistry teacher, I observe that in high school Chemistry textbooks, particle diagrams are used sparingly and sporadically as concept illustrations and as summative assessment items. Very few chemistry textbooks make extensive use of particle representations, but they are not accessible by all teachers. In their action research, Kimberlin and Yezierski (2015) designed and provided evidence for the effectiveness of two particulate level inquiry-based lessons. Unfortunately, these lessons could not be accessed online. Without classroom-ready and easily accessible materials, recommendations to incorporate particulate ideas in Stoichiometry lessons create gaps in the literature.

Particle Diagrams

A particle diagram is a model that usually describes the arrangement and movement of particles in a substance (Pearson, 2015) . The particles are represented as circles that are either drawn individually or in groups of two or more depending on what substance they constitute. The most science lessons the diagram is used to explain the physical properties of solids, liquids, and gases. However, in stoichiometry, it is used to show the composition of substances involved in chemical reactions. It shows the number and types of particles that are make up the reactants and products in the chemical reactions. Examples of particle diagrams representing an element, a compound, and a mixture are shown below.

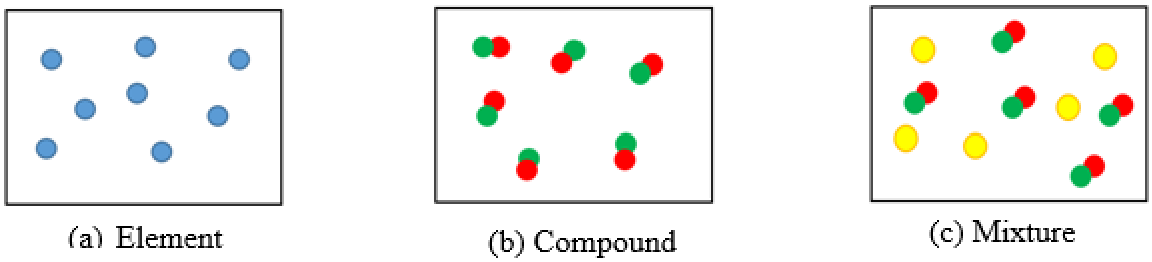

Figure 1. element, compound, mixture

METHODS

Research Questions

The following questions guide the researcher in the study.

Research Question 1. To what extent does the use of particle diagrams affect students' conceptual understanding of representative particle, mole ratio, limiting reagent, and theoretical yield?

Research Question 2. What are the students' attitudes towards the use of particle diagrams?

Research Design

The study employed, pre-experimental one-group pre-test post-test design (or paired-sample design). In this design, the students' conceptual understanding of stoichiometry was measured on one group of grade 10 students once before treatment was implemented (pretest), and once after it was implemented (posttest). Conclusions about the effects of the treatment were formulated based on the difference between the pretest and posttest data.

The researcher adopted this design for several important reasons. First, this design allowed the study to be done in a real classroom setting, within a single class without having to separate students, and during school hours without disrupting the smooth running of any classes or school programs. Second, the treatment itself could be easily incorporated in the Chemistry lessons without compromising real learning time for the students. A third reason was that the researcher had no control over the number of students who enrolled in General Chemistry class and since the number was small (thirteen students), it was more feasible to adopt a one-group design.

Treatment Conditions

The treatment engaged students in simple, non-intrusive activities compiled in a booklet entitled Thinking the Particulate Way (TPW). The booklet contains 54 particle diagrams (also called particulate diagrams or submicroscopic diagrams) related to topics and concepts of Stoichiometry. The method of instruction for the unit of stoichiometry traditionally included the interactive lecture method, modeling problem-solving, peer coaching, laboratory activities and very minimal use of particulate diagrams drawn on the whiteboard, and shown on powerpoints. In this treatment-added approach, the same strategies were used but with the integration of the information and exercises contained in the TPW booklet wherever and whenever they were relevant in the lessons. The booklet served as supplementary materials that allow students ample opportunities to examine the submicroscopic basis of concepts related to stoichiometry, specifically the concepts of representative particles, mole ratio, limiting reagent, and theoretical yield.

The TPW booklet is divided into four sections. Each section includes a topic and one Stoichiometry concept that is related to the study.

Population and Sample

The sample for this study was thirteen 10th grade students who enrolled in the General Chemistry class for the academic year 2018-19 at AIMS. The sample was selected using the non-random, convenience sampling technique. The researcher sampled thirteen 10th grade Chemistry students who were conveniently available and happened to be her students at the time of the study. By this sampling technique, it was not possible to specify the target population from which this sample was drawn. However, generalizability was not a concern for the researcher because her interest was only in discovering the effects of a pedagogical approach on a specific group of individuals at AIMS only to whom the results were relevant.

Instrumentation

Conceptual Stoichiometry Test (CST) Pretest and Posttest

To determine the effects of the use of particle diagrams on students' conceptual understanding of Stoichiometry, an improved version of a published instrument called Conceptual Stoichiometry Test (CST) designed by Wood and Breyfogle (2006), and improved by Kimberly and Yezierski (2015). Stoichiometric concepts addressed and measured by the 10-item test were: a) Representative Particles, b) Mole Ratio, c) Limiting Reagent, and d) Theoretical Yield.

The CST test was piloted with nine grade 10 students enrolled in Physical Science class at AIMS. Apart from question reorganization, there was no need to change other aspects of the test after the pilot test.

Attitudes Towards the Use of Particle Diagrams Questionaire

A 10-item Attitude Towards the Use of Particle Diagrams (ATPD) questionnaire was administered to the students at the end of the Stoichiometry unit to determine their attitudes to the use of particle diagrams, and whether or not it helped them understand Stochiometric concepts. The researcher herself developed the 12-item questionnaire. Each item was rated on a Likert scale using five response categories; Strongly Agree (SA), Agree (A), Not Sure (NS), Disagree (D), and Strongly Disagree (SD).

A pilot study was carried out for the questionnaire in which ten grade twelve students were the respondents. The results of the pilot study suggested that no change in the questionnaire was necessary.

Data Collection

The researcher applied two methods of data collection techniques – pretest/posttest and questionnaire. The pretest was administered to the participants in one class period before their lessons on The Mole, Chemical Reactions, and Stoichiometry. During the treatment period, Chemistry classes continued as scheduled, and the TPW companion booklet was used in all of the Chemistry lessons as a source of content knowledge and illustrations, for explanation and reinforcement of concepts, as well as for assessments. After the approximately five-week duration, the participants took the posttest and completed the questionnaire.

Data Analysis

Data collected from the Conceptual Stoichiometry Test (CST) were analyzed using the paired-sample (correlated) t-test. Data collected from the Attitude Towards the Use of Particle Diagrams (ATPD) questionnaire were analyzed using descriptive statistics in the forms of means, standard deviations, and percentages

RESULTS

Results of paired-samples t-test

Analysis of the participants' pre and post-test mean scores on the four concepts of Stoichiometry was carried out using SPSS. Table 1 displays the descriptive statistics for the pre and posttest conditions. While it appears that the participants performed differently under the pretest and posttest conditions, further information in the form of inferential statistics is needed to determine whether there is any significant difference between the participants' pretest and posttest means on all four concepts.

A paired-samples t-test was conducted to determine whether there is a statistically significant difference in the pretest and posttest mean scores of each of the four concepts of Stoichiometry listed in research question 1. Table 2 displays the results of the paired sample t-test.

Table 2 shows that for all the concepts (pairs 1 – 4), the p (probability) value is substantially smaller than the specified alpha value of .05, which means there is a very significant difference between the pretest and posttest scores. Combining the information from Table 1 and Table 2, the results of the analysis are as follows.

For the concept of Representative Particles (Pair 1), there was a statistically significant increase in pretest scores prior to intervention ($M = 7.46$, $SD = 2.73$) to posttest scores after intervention ($M = 11.00$, $SD = 2.38$), $t(12) = -5.558$, $p < .000$ (two-tailed). The mean increase in posttest scores was 2.31, with a 95% confidence interval ranging from -4.93 to -2.15.

For the concept of Mole Ratio (Pair 2), there was a statistically significant increase in pretest scores prior to intervention ($M = 16.31$, $SD = 3.68$) to posttest scores after intervention ($M = 18.62$, $SD = 2.36$), $t(12) = -3.476$, $p < .005$ (two-tailed). The mean increase in posttest scores was 3.54 with a 95% confidence interval ranging from -3.75 to -0.86.

For each of the concepts of Limiting Reagent and Theoretical Yield, there was a statistically significant increase in pretest scores prior to intervention ($M = 5.77$, $SD = 1.42$) to posttest scores after intervention (M = 7.31, SD = 2.06), t (12) = -3.237, $p < .007$ (two-tailed). The mean increase in posttest scores was 1.54 with a 95% confidence interval ranging from -2.57 to -0.50.

Although the results presented above, tell us that the difference obtained in each concept pair is significant, it does not tell us about the magnitude of the intervention's effect. The effect size was calculated using the Eta squared, and the results are presented in Table 3.

Table 3 shows that the treatment has an effect size of 1.54 on the concept of Representative Particles, .96 on the concept of Mole Ratio, .90 on the concept of Limiting Reagent and .90 on the concept of Theoretical Yield. Given that the guidelines for interpreting Eta value are: .01 = small effect, .06 = moderate effect, .14 = large effect (Pallant, 2011), we can conclude that the treatment had a large effect on the difference between the CST scores on each concept obtained before and after the intervention.

Analysis and Interpretation of ATPD Survey Results

A total of 13 survey forms were distributed, and all 13 were completed and were the base for computing the results. Results show that the responses most frequently selected by the participants were Strongly Agree (41.0%), followed by Agree (37.2%) and Not Sure (16.7%). The responses least frequently selected were Disagree (3.8%) and Strongly Disagree (1.3 %). The results of the questionnaire were further analyzed by concept, as shown in Tables 4 – 7.

Table 4 shows that more than eighty percent (84.6% - 100.0%) of the participants responded with Agree and Strongly Agree, and scored between 4 – 5 (4.38 – 4.62) on a 5-point Likert scale on the concept of Representative Particles. These results suggest that the majority of the participants agreed that the use of particle diagrams helped develop an understanding of this concept.

Table 5 shows that more than sixty percent (61.6% - 100.0%) of the participants responded with Agree and Strongly Agree, and scored between 3 – 5 (3.69 – 4.54) on a 5-point Likert scale on the concept of Mole Ratio. These results suggest that the majority of the participants agreed that the use of particle diagrams helped develop an understanding of this concept.

Table 6 shows that more than eighty-five percent (85.6% - 92.3%) of the participants responded with Agree and Strongly Agree, and scored between 4 – 5 (4.31 – 4.62) on a 5-point Likert scale on the concept of Limiting Reagent. These results suggest that the majority of the participants agreed that the use of particle diagrams helped develop an understanding of this concept.

Table 7 shows that less than fifty percent (30.8% - 46.2%) of the participants responded with Agree and Strongly Agree, and scored between 3 – 4 (3.08 – 3.15) on a 5-point Likert scale on the concept of Theoretical Yield. These results suggest that less than half of the participants agreed that the use of particle diagrams helped develop an understanding of this concept.

Reliability analysis was carried out on the ATPD scale. Cronbach's alpha shows the ATPD questionnaire to have acceptable internal consistency, $\alpha = 0.80$. This result indicates that the 12 items in the questionnaire are highly interrelated and are reliably measuring the underlying construct (Pallant, 2011). In this study, the construct was the participants' attitude towards the use of particle diagrams in understanding concepts of Stoichiometry

DISCUSSION

The purpose of this study is to investigate the effects of using particle diagrams on the conceptual understanding of stoichiometry among tenth-grade students at AIMS, Muak Lek, Thailand. Specifically, the study examines the extent to which the use of particle diagrams affects the students' conceptual understanding of representative particles, mole ratio, limiting reagent, and theoretical yield. It further examines the attitudes of the students towards the use of particle diagrams in their learning of these concepts.

Findings from this study contribute to AIMS and the local learning community in the following ways.

AIMS and Other Schools**.** This study will contribute to the development of science education at AIMS and other high schools. The researcher hopes that this research will encourage Science educators to explore and adapt research-based pedagogical recommendations to verify their effectiveness on the learning of their students in their school settings.

AIMS Science Teachers**.** The results of the study will help AIMS Science teachers evaluate the impact of using particle diagrams in developing students' conceptual understanding of stoichiometry. The study will also help teachers establish the extent to which particulate ideas should be incorporated into instruction to maximize concept attainment while avoiding cognitive overloading. Therefore, this study can help teachers develop new and specific strategies for enhancing conceptual learning in Chemistry.

AIMS Chemistry Students. This study encourages students to approach stoichiometric problems from the particulate perspective. Training students to think "in a particulate way" will build the conceptual foundation not only for stoichiometry but also for other high school

Chemistry topics and will be beneficial for more advanced studies of the subject. This study can also help students rectify their misconceptions about some concepts of Stoichiometry, specifically the concepts of representative particles, mole ratio, limiting reagent, and theoretical yield. The researcher also hopes that this study will help students develop appreciation and preference for more in-depth, conceptual understanding rather than superficial learning.

Summary of Results

The results obtained from this study are summarized as follows.

The was a significant difference between CST scores on all four concepts of Stoichiometry before and after the intervention. The effect of the intervention on each CST score difference for each concept was substantial. In short, the use of particle diagrams in the instruction of stochiometry significantly improved AIMS students' understanding of the concept of representative particles, mole ratio, limiting reagent, and theoretical yield.

The results of the ATPD questionnaire indicate that generally, the participants demonstrated a favorable attitude towards the use of particle diagrams in the instruction of stoichiometry. The majority of the participating AIMS students agreed that the use of particle diagrams helped them develop an understanding of the concepts of representative particles, mole ratio, and limiting reagent. However, less than half of the students agreed that the use of particle diagrams helped them develop an understanding of the concept of theoretical yield.

Studies have revealed that most high school chemistry students lack the conceptual understanding of stoichiometry necessary for answering conceptual questions correctly. Studies also have found that an understanding of the submicroscopic composition of chemical elements or/and compounds that make up the reacting and resulting substances in chemical reactions is an essential prerequisite to interpreting and solving all stoichiometric problems, especially the conceptual ones. In this study, the submicroscopic composition of matter substances was represented by particle diagrams. Results from this study show that these findings also apply to high school chemistry students at AIMS. These students' responses to the use of particle diagrams matched with what was already described in the literature and confirmed the positive effects of using particulate models to enhance understanding of chemistry concepts.

Limitations

They are a few limitations to the study. The first limitation is that the research focuses on a small population sample of only thirteen high school students enrolled in Chemistry class at only one international school, namely the Adventist International Mission School, in Thailand. The second limitation is that this study involves only one Chemistry teacher. Because of these limitations, the results of the study will have limited generalizability across students, teachers, and schools. However, the scope of the study is confined to the effects of using particle diagrams on the conceptual learning of AIMS high school Chemistry students only. Therefore, generalizability over general populations is both inconsequential and not an expected attribute of this study.

Because of its small size, the study has a reduced statistical power to detect the actual difference between students' conceptual understanding before and after the use of particle diagrams. Moreover, the use of a one-group pretest-posttest design in this study could compromise its internal validity. The researcher recognizes that the difference between the pretest and posttest data may not be representative of the actual effect of the use of particle diagrams and may be attributed to alternative factors such as history, maturation and the testing itself.

Recognizing these limitations, the researcher is cautious about inferring causality from the data, nor does she intend to treat it as conclusive evidence for or against the use of particle diagrams in Stoichiometry lessons at AIMS.

Although the researcher planned the study to serve more of a first -hand experience for both teacher and students at AIMS in using particle diagrams intentionally in stoichiometry lessons, the data collected can be useful for designing more extensive confirmatory studies or similar studies at AIMS or other high schools in Thailand in the future

Conclusion

As mentioned earlier, the first objective of the study is to investigate the extent to which the use of particle diagrams affect AIMS students' conceptual understanding of stoichiometry. From the results of the inferential analysis, it shows that the use of particle diagrams in the instruction of stoichiometry leads to a better understanding of the concepts of representative particles, mole ratio, limiting reagent, and theoretical yield.

The second objective of the study is to evaluate the attitudes of AIMS students towards the use of particle diagrams in stoichiometry instruction. The results indicate that all students find the particle diagrams helpful in enhancing their understanding of the concepts of representative particles, mole ratio, and limiting reagent but not helpful in improving their understanding of the concept of the theoretical yield.

In conclusion, both objectives of the study have been achieved.

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TABLES AND FIGURES

Table 1. **Paired Sample Statistics**

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RepPartPre	7.46	13	2.73	.76
	RepPartPost	11.00	13	2.38	.66
Pair 2	MoleRatioPre	16.31	13	3.68	1.02
	MoleRatioPost	18.62	13	2.36	.66
Pair 3	LimReaPre	5.77	13	1.42	.39
	LimReaPost	7.31	13	2.06	.57
Pair 4	YieldPre	5.77	13	1.42	.39
	YieldPost	7.31	13	2.06	.57

Table 2. **Paired Differences**

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	RepPartPre - RepPartPost	-3.53846	2.29548	.63665	-4.92561	-2.15132	-5.558	12	.000
Pair 2	MoleRatioPre - MoleRatioPost	-2.30769	2.39390	.66395	-3.75431	-.86107	-3.476	12	.005
Pair 3	LimAgentPre - LimAgentPost	-1.53846	1.71345	.47522	-2.57389	-.50304	-3.237	12	.007
Pair 4	YieldPre - YieldPost	-1.53846	1.71345	.47522	-2.57389	-.50304	-3.237	12	.007

Table 3. **Effect Size**

Descriptive analysis for the concept of representative particles (n=13)

Statement	M	SD	%[a]
1. Particle diagrams help me visualize the particles that make up compound, mixture, and elements.	4.62	0.51	100.00
2. Particle diagrams help me differentiate among atoms, molecules, ions, and combinations of these.	4.46	0.78	84.6
3. Particle diagrams help me understand what happens to the particles of reactants during chemical reactions.	4.38	0.65	92.3

Note: Percent Agree/Strongly Agree

Table 4. **Descriptive Analysis for the Concept of Representative Particles (n=13)**

Effect Size

Effect Size	Concept	ES
1	Representative Particle	1.54
2	Mole Ratio	.96
3	Limiting Reagent	.90
4	Theoretical Yield	.90

Table 5. **Descriptive Statistics for Mole Ratio (n=13)**

Descriptive statistics for mole ratio (n=13)

Statement	M	SD	%[a]
4. Particle diagrams help me understand what the coefficients in balanced chemical equations represent.	4.23	1.01	76.9
5. Particle diagrams help me determine how many of each kind of atom takes part in a chemical reaction in the lowest whole number ratio.	4.15	0.69	84.6
6. Particle diagrams help me relate coefficients to mole ratio.	3.69	0.86	61.6
7. Particle diagrams help me determine the amounts of substances needed or produced in a chemical reaction.	4.54	0.52	100.00

[a]Percent Agree/Strongly Agree

Table 6. **Descriptive Statistics on Limiting Agent (n=13)**

Descriptive statistics on Limiting Agent (n=13)

Statement	M	SD	%[a]
8. Particle diagrams show that in some chemical reactions, reactants are not necessarily all used up.	4.62	0.65	92.3
9. Particle diagrams help me identify the reactant that is all used up first (limiting reagent).	4.46	0.66	92.3
10. Particle diagrams help me identify the reactant that is NOT all used up (excess reagent).	4.31	0.75	85.6

[a]Percent Agree/Strongly agree

Table 7. **Descriptive Statistics of Theoretical Yield (n=13)**

Descriptive statistics of Theoretical Yield (n=13)

Statement	M	SD	%[a]
11. Particle diagrams help me understand the difference between theoretical yield and actual yield.	3.15	0.99	46.2
12. Particle diagrams help me identify which reactant determines the theoretical yield.	3.08	1.04	30.8

[a]Percent Agree/Strongly agree