# EFFECTS OF USING PARTICULATE MODEL AS A TEACHING STRATEGY ON THE LEARNING OF WRITING CHEMICAL FORMULAE AND BALANCING CHEMICAL EQUATIONS

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**Abstract**

This study investigates the effects of an innovative teaching strategy, namely Particle Teaching Strategy, which incorporates both the microscopic and symbolic levels of chemistry during instruction, on the students' chemical knowledge, conceptual understanding and problem solving performance. The topic for the study is writing chemical formulae and balancing chemical equations. A total of 74 secondary three students from two intact classes in a government boys' school were involved in this study. One of the two classes was taught using the Particle Teaching Strategy (treatment group), while the other class was taught using the traditional teaching method (control group). Three test instruments, namely Chemical Knowledge Test, Conceptual Understanding Test and Problem Solving Test, were designed and administered as pre-tests to the students before teaching the topic and as post-tests after the students were taught the topic. The results of the study and its implications for teaching chemistry will be discussed.

## Theoretical Framework

In the past few years, research studies had found that students had difficulties in visualising particles' behaviour and arrangement in a chemical reaction microscopically as well as in relating chemical equation as a symbolic representation of chemical reaction at the microscopic level. When Yarroch (1985) examined 14 high school chemistry students who had been successful in balancing chemical equations, he found that more than 50% of these students were unable to draw correct diagrammatic representation of the symbolic chemical equations at the molecular level. In another study by Ahtee and Varjola (1998), they found that the first year senior secondary students and first year general chemistry undergraduate could write a chemical equation using the chemical symbols, but these students failed to describe what was actually going on in the reaction at a microscopic level.

Similarly, the study by Wolfer and Lederman (2000), which looked into students' ability to connect between conceptual and computational understandings in stiochiometry, had found that most of the students were unable to depict the microscopic representation of a chemical reaction between chlorine molecules and an excess of aluminium atoms, given the symbolic chemical equation. From their interview with these students, Wolfer and Lederman found that they could not understand how the "two chlorine atoms in each chlorine molecule were split to give three chloride ions in each aluminium chloride produced".

Nurrenberg and Pickering (1987) conducted a study to investigate on whether students who were successful in solving problems would have acquired an understanding of the chemical concepts involved in the problems. They found that most of these students who were successful problem solvers lacked conceptual understanding of symbolic chemical equations at the microscopic level. Therefore, it is evident from the review of the above research studies that students often treat chemical equations as mathematical puzzles in which the number of the same atoms on both sides of the chemical equations have to be equal, rather than thinking of the equation as a representation of a dynamic and interactive chemical process.

Georgiadou and Tsaparlis (2000) evaluated the effectiveness of two teaching methods in enhancing Greek lower secondary school students' learning of the abstract and complex concepts of chemistry. One of the teaching methods was based on the developmental psychological theories proposed by the psychologist Robbie Case (Case, 1978), while the other was based on the macroscopic, microscopic and symbolic levels of chemistry as proposed by Alex H. Johnstone (Johnstone, 2000). In the teaching method based on Case's proposal, it showed how the students could improve their learning of chemistry through guided discovery experiments, construction of solid models by students and concept maps. In the other teaching method based on Johnstone's proposal, known as "three-cycle", the students were taught in the first cycle at the macroscopic level, this was followed by going through the same material again in the second cycle at the symbolic level and finally in the third cycle, the same material was covered at the microscopic level. The results showed that the teaching method which involved the three levels of chemistry was most effective in enhancing students' learning of chemistry. The process of going through the same material three times at the different levels (macroscopic, microscopic and symbolic) could help students to make the mental links between the three levels of chemistry, thus strengthening their conceptual understanding

As suggested by Ben-Zvi, Eylon and Silberstein (1987), an appropriate interpretation of the chemical information underlying an equation requires learners to understand many aspects of chemistry such as (i) the interactive nature of the chemical reaction represented by the equation, (ii) the quantitative relationships among the reactant and product particles (meanings of coefficients and subscripts), and (iii) the structure of the reactants and products. This explains why many students find it difficult to understand the chemistry concepts underlying the chemical equations. However, the conceptual understanding of chemical equations can be improved, if the relationship between the mechanics of balancing equations and the underlying concepts at the microscopic level are constantly emphasized in the teachers' instruction (Yarroch, 1985). As such, this study intended to investigate the effect of a teaching strategy known as Particle Teaching Strategy (PTS), which enabled students to visualise particles' behaviour and arrangement in a chemical reaction microscopically as well as in relating chemical equation as a symbolic representation of chemical reaction at the microscopic level, on students' acquisition of chemical knowledge, conceptual understanding and problem solving performance.

Three research questions for this study are as follows:

Q1. Is there a significant difference in the chemical knowledge of the topic on writing chemical formulae and balancing chemical equations among the students who are taught using Particle Teaching Strategy and those who are taught using Traditional Teaching Strategy?

Q2. Is there a significant difference in the conceptual understanding of the concepts of the topic on writing chemical formulae and balancing chemical equations among the students who are taught using Particle Teaching Strategy and those who are taught using Traditional Teaching Strategy?

Q3. Is there a significant difference in the problem solving performance among the students who are taught using Particle Teaching Strategy and those who are taught using Traditional

Teaching Strategy for the topic of writing chemical formulae and balancing chemical equations?

## Method

*Sample*

A total of 74 secondary three (equivalent to Grade 9) pure chemistry students, with an average age of 15, from a government boys' school were involved in this study. There are four levels of education in this government boys' school. The levels comprise of secondary one, two, three and four with age ranging between thirteen and sixteen years. Two intact classes at the secondary three level were chosen to form the treatment group and control group. The subjects were taken from two intact classes so as not to upset the normal school routine and organisation. Thus a smooth incorporation of the treatment using Particle Teaching Strategy into the science curriculum was ensured. The numbers of students in the treatment and control groups were 39 and 35 respectively.

*Research Design*

A quasi-experimental design was adopted since random assignment of subjects was not possible as intact classes were used. The non-equivalent control-group design was used. The same instruments were used for the pre-test and post-test for both the treatment and control groups. The pre-test and post-test measured the three dependent variables, namely Chemical Knowledge Performance (CKP), Conceptual Understanding Performance (CUP) and Problem Solving Performance (PSP). CKP measures the extent of the chemical knowledge attained by the students from the topic learnt. CUP measures the extent of understanding attained by the students on the symbolic chemical equations at the microscopic level, in terms of particles. PSP measures students' performance of problem-solving in applying the chemical knowledge and concepts learnt to successfully solve problems.

The topic selected for this study was on the writing of chemical formulae and balancing of chemical equations. It is part of the syllabus specified by the General Cambridge Examination Ordinary (GCE 'O') Level Examination Syndicate (Ministry of Education, 2002) for the pure chemistry subject. This topic is typically introduced and studied at the secondary three level as the foundation for chemistry topics such as stoichiometry.

The content knowledge, examples, homework and reading materials used in the study were identical for both the control and treatment groups. The same teacher (one of the authors, referred to as researcher from here onward) taught both the treatment and control groups so as to minimize the individual differences in teaching styles and in the delivery of course content for the two groups. The treatment group was instructed using the Particle Teaching Strategy (PTS), while the control group was instructed using the Traditional Teaching Strategy (TTS). PTS used microscopic and symbolic representations of reactant and product particles of various chemical reactions in teaching the content knowledge to the students in the treatment group. Magnetic buttons, representing particles, were used to explain and illustrate concepts to students. Students had also used magnetic buttons to construct their idea of how reactants particles behaved in chemical reactions. This was further reinforced by drawing the reactants and products particles in terms of circles on the board and worksheets, before representing the reaction in chemical symbols and formulae in a balanced equation. Thus, there was an emphasis on the particles' behaviour and arrangement and the relationship between the microscopic and symbolic levels of chemistry during instruction. PTS provided students with the opportunity to visualize how particles behaved in a chemical reaction (microscopic representation) and to understand the chemistry behind it, before they penned down the balanced chemical equation (symbolic representation) that represented the reaction. In addition, PTS explicitly taught the linkage between the microscopic and symbolic levels of chemistry. On the other hand, Traditional Teaching Strategy (TTS) implemented in the control group focused on the teaching of similar content knowledge using only the symbolic representations of reactants and products of the same chemical reactions taught to students in the treatment group. In short, students in the control group were given explanation of the concepts at the symbolic level of chemistry using only chemical symbols and formulae. A summary of the two different teaching strategies and materials used in the treatment and control groups is shown in Table 1.

**Table 1**: *Summary of teaching strategies and materials used in the treatment and control group*

| Sample | Teaching Strategy | Features of the Teaching Strategy | Teaching materials used |
|---|---|---|---|
| **Treatment** | Particle Teaching Strategy (PTS) | Microscopic and symbolic level of chemistry | Coloured magnet buttons of various sizes, round metal plates, lesson notes, and worksheets |
| **Control** | Traditional Teaching Strategy (TTS) | Symbolic level of chemistry | lesson notes, and worksheets |

The teaching strategies were implemented over a time frame of four weeks, excluding the administration of the pre-test and post-test. Each group of the students (treatment and control groups) was given four periods of chemistry theory lesson per week on this topic with each period of lesson lasted for thirty-five minutes.

*Instrumentation and Administration*

The three dependable variables, CKP, CUP and PSP, were measured by three instruments, namely Chemical Knowledge Test (CKT), Conceptual Understanding Test (CUT) and Problem Solving Test (PST). All the three instruments were designed based on the content of the topic on writing chemical formulae and balancing chemical equations and were validated. With the exception of CKT, the instruments were short structured questions type of tests. Some of these short structured questions were adapted from some research studies (Nurrenbern & Pickering, 1987; Nakhleh, 1993). The scoring systems for the three instruments were devised. The scoring system for CKT is based on students' correct responses to the twenty multiple choice questions. For CUT, the scoring of the test items in this instrument was devised based on three modes of responses: drawing of microscopic representation, writing and balancing chemical equations and written explanation. In PST, students' responses are graded using three scoring methods: (a) scores for correct answers obtained; (b) explicit use of specific chemical knowledge; and (c) correct application of specific chemical knowledge.

The three test instruments were administered as pre-tests to the students before teaching the topic. This was followed by administering the same three test instruments as post-tests after the students were taught the topic. The time allocations for administering these three instruments were (a) CKT : 30 mins; (b) CUT : 40 mins; (c) PST: 30 mins.

## Results

*Procedure for data analysis*

The Cronbach α reliabilities were calculated for all the three instruments. Descriptive statistics such as the means, standard deviations and maximum score possible for the tests were also calculated. For the inferential statistics, a multivariate analysis of variance (MANOVA) of the pre-test variables scores (CKP, CUP and PSP) comparing the treatment and control groups was first conducted to identify any pre-existing differences. Once the initial pre-test scores differences were identified, a multiple analysis of covariance (MANCOVA) of the post-test variables scores was then conducted taking into consideration the covariates identified. This would determine the effects of the treatment on the students' chemical knowledge performance, conceptual understanding performance and problem solving performance.

*Reliability of the Instruments*

Table 2 provides a summary of the reliabilities of the three instruments, CKT, CUT and PST, in terms of Cronbach alpha (α) reliability coefficients and the total number of items involved in the scoring systems for all the three instruments.

**Table 2:** *Reliabilities of the test instruments*

| Test Instrument | Cronbach alpha (α) | No. of items |
|---|---|---|
| Chemical Knowledge Test (CKT) | 0.61 | 20 |
| Conceptual Understanding Test (CUT) | 0.70 | 17 |
| Problem Solving Test (PST) | 0.89 | 9 |

*Descriptive Statistics*

The means, standard deviations and maximum scores possible of all the variables of the pre-test and post-test for both the control and treatment groups are shown in Tables 3 and 4 respectively. The mean scores of the pre-test and post-test of Problem Solving Test (PST) were generally low. This indicates that the students were weak in problem solving.

**Table 3:** *Descriptive Statistics for the pre-test variables scores between the treatment and control groups.*

| Instrument | Variable | Treatment Group Mean (S.D) (N = 39) | Control Group Mean (S.D.) (N = 35) | Max Score Possible |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| CKT | CKP | 10.90 (2.77) | 10.00 (3.11) | 20 |
| CUT | CUP | 20.26 (5.59) | 18.94 (7.00) | 57 |
| PST | PSP | 5.00 (3.32) | 2.29 (3.04) | 33 |

**Table 4:** *Descriptive Statistics for the post-test variables scores between the treatment and control groups.*

| Instrument | Variable | Treatment Group Mean (S.D) (N = 39) | Control Group Mean (S.D.) (N = 35) | Max Score Possible |
|---|---|---|---|---|
| CKT | CKP | 16.03 (2.44) | 15.69 (2.68) | 20 |
| CUT | CUP | 36.31 (7.33) | 31.23 (5.64) | 57 |
| PST | PSP | 17.05 (6.02) | 12.09 (4.55) | 33 |

*MANOVA Analysis*

A multivariate analysis of variance (MANOVA) of the pre-test variables scores was conducted to identify any pre-existing differences in Chemical Knowledge Performance (CKP), Conceptual Understanding Performance (CUP) and Problem Solving Performance (PSP) between the treatment and control groups. The results of MANOVA showed no significant difference in the pre-test scores of CKP and CUP between the treatment and control groups. However, there existed a significant difference in pre-test scores of PSP between the two groups as the P-value is 0.00 (Table 5). This indicated that PSP had a pre-existing difference between the treatment and control groups. Thus, pre-test scores of PSP had to be taken into consideration when the data (post-test scores of the respective three dependent variables) were further analyzed to determine the effectiveness of the Particle Teaching Strategy on CKP, CUP and PSP. Table 5 shows the results of the MANOVA analysis for the pre-test scores of the three variables, CKP, CUP and PSP.

**Table 5:** *MANOVA on the pre-test scores of the three dependent variables (CKP, CUP & PSP) between the treatment and control groups*

| Source | Type III SS | df | MS | F-Ratio | P-vaule |
|---|---|---|---|---|---|
| CKP | 14.856 | 1 | 14.856 | 1.73 | 0.193 |
| CUP | 31.83 | 1 | 31.83 | 0.80 | 0.373 |
| PSP | 119.14 | 1 | 119.14 | 40.71 | 0.00 |

*MANCOVA Analysis*

Three null hypotheses were formulated and tested to confirm statistically the answers to the Research Questions 1, 2 and 3 of this study. Null Hypothesis I, II and III were designed to test for the effect of Particle Teaching Strategy (PTS) on CKP, CUP and PSP respectively. A multiple analysis of covariance (MANCOVA) of the post-test scores of the three dependent variables (CKP, CUP and PSP), using the pre-test scores of PSP as the covariate, was conducted to determine any significance differences of the three variables between the treatment and control groups.

*Effect of PTS on Chemical Knowledge Performance*

Null Hypothesis I

*"There is no significant difference in the Chemical Knowledge Performance (CKP) between the two groups of students who were taught using Particle Teaching Strategy (PTS) and Traditional Teaching Strategy (TTS) respectively."*

The results of MANCOVA analysis on the post-test scores of Chemical Knowledge Performance (CKP), using the pre-test scores of PSP as covariate, are shown in Table 6. It was found that the P-value is 0.949. Thus, the null hypothesis was accepted. This indicates that Particle Teaching Strategy (PTS) has no effect on students' Chemical Knowledge Performance

**Table 6:** *MANCOVA on the post-test scores of the CKP, using covariate of pre-test scores of PSP, between the treatment and control groups*

| Source | Type III SS | df | MS | F-Ratio | P-value |
|---|---|---|---|---|---|
| PSP (Pre-test scores, covariate) | 4.877 | 1 | 2.773 | 0.42 | - |
| Treatment (Between) | 0.028 | 1 | 31.83 | 0.00 | 0.949 |
| Error (Within) | 467.74 | 71 | 6.588 | | |
| Total | 472.65 | 73 | | | |

*Effect of PTS on Conceptual Understanding Performance*

Null Hypothesis II

*"There is no significant difference in the Conceptual Understanding Performance (CUP) between the two groups of students who were taught using Particle Teaching Strategy (PTS) and Traditional Teaching Strategy (TTS) respectively."*

The results of MANCOVA analysis on the post-test scores of Conceptual Understanding Performance (CUP), using the pre-test scores of PSP as covariate, are shown in Table 7. CUP was significant at 0.04 confidence level. This indicates that Particle Teaching Strategy (PTS) has an effect on students' Conceptual Understanding Performance. Thus, the null hypothesis was rejected.

**Table 7:** *MANCOVA on the post-test scores of the CUP, using covariate of pre-test scores of PSP, between the treatment and control groups*

| Source | Type III SS | df | MS | F-Ratio | P-value |
|---|---|---|---|---|---|
| PSP (Pre-test scores, covariate) | 320.57 | 1 | 35.98 | 0.83 | - |
| Treatment (Between) | 191.27 | 1 | 191.27 | 4.40 | 0.04 |

| | | | | | |
|---|---|---|---|---|---|
| Error (Within) | 3086.5 | 71 | 43.47 | | |
| Total | 3598.34 | 73 | | | |

*Effect of PTS on Problem Solving Performance*

Null Hypothesis III

*"There is no significant difference in the Problem Solving Performance (PSP) between the two groups of students who were taught using Particle Teaching Strategy (PTS) and Traditional Teaching Strategy (TTS) respectively."*

The results of MANCOVA analysis on the post-test scores of Problem Solving Performance (PSP), using the pre-test scores of PSP as covariate, are shown in Table 8. The P-value obtained is 0.231. This indicates that Particle Teaching Strategy (PTS) has no effect on students' Problem Solving Performance. Thus, the null hypothesis was accepted. However, the mean post-test score of PSP for the treatment group was relatively higher than that for the control group (refer to Table 4).

**Table 8:** *MANCOVA on the post-test scores of the PSP, using covariate of pre-test scores of PSP, between the treatment and control groups*

| Source | Type III SS | df | MS | F-Ratio | P-value |
|---|---|---|---|---|---|
| PSP (Pre-test scores, covariate) | 167.58 | 1 | 71.33 | 10.40 | - |
| Treatment (Between) | 10.00 | 1 | 10.00 | 1.46 | 0.231 |
| Error (Within) | 487.07 | 71 | 6.86 | | |
| Total | 664.65 | 73 | | | |

## Discussion

This study intended to investigate the effects of Particle Teaching Strategy (PTS) on the students' chemical knowledge performance, conceptual understanding performance and problem solving performance on the topic of writing chemical formulae and balancing chemical equations. It was found that PTS is effective in helping students to acquire conceptual understanding of chemistry knowledge in general, writing and balancing chemical equations in particular. PTS had made the invisible and untouchable atoms, molecules and ions more accessible to the students' perception and experience through the use of coloured magnet buttons and worksheets with the emphasis on microscopic representation of chemical reactions. This finding confirms the study by Williamson & Abraham (1995) who suggests that when the students are exposed to the teaching strategy with emphasis on particles' behaviour and arrangement in chemical processes during instruction, they are more able to form appropriate mental models on particulate nature of matter. Thus, whenever students construct concrete model of microscopic representations of reactions using magnetic buttons, they are able to visualise how the particles interact and re-arrange in reactions and this enhances their conceptual understanding.

In contrast, PTS did not seem to have any effect on the students' chemical knowledge and problem solving ability. As the basic chemical facts taught were emphasized to similar extent in both teaching strategies (Particle Teaching Strategy and Traditional Teaching Strategy), this could probably explain why the different teaching strategies had made no difference in their learning of chemical knowledge or facts between the treatment and control groups. Furthermore, the students were tested only on the basic content knowledge of the topic taught in the test instrument CKT, they could learn it easily regardless of the teaching strategies implemented.

There are three possible factors which could have attributed to the finding on the effect of PTS on students' problem solving ability. Firstly, students might have the tendency to rely on mathematical manipulation to solve the problems given in the test instrument PST. The problems in PST required students to look into the numbers of particles reacted or produced in the various chemical reactions with symbolic chemical equations provided. As symbolic chemical equations were provided, students might have the tendency to use mathematical manipulation to derive at the answers rather than relying on understanding the microscopic representations of the reactions. Hence, the problems in PST should be structured in such a way that students could not obtain the answers easily through mathematical manipulation. Perhaps a description by the students on the steps he/she had taken to derive at the answers should be included in PST so as to assess their thought processes and hence determine whether they had solved the problems through conceptual understanding of the symbolic chemical equations provided.

Secondly, the students in the treatment group might need more time and practices to get use to the new learned strategy of drawing microscopic representations. For instance, more examples and questions/problems which required drawings of microscopic representations to derive at the solution can be incorporated during instruction. By doing so, students can be encouraged to adopt this practice and be able to see the application of thinking and looking beyond the symbolic chemical equations in solving problems. Thirdly, problem solving skills cannot be left to chance, it has to be taught explicitly (Lee, Goh, Chia & Chin, 1996; Noh & Scharmann, 1997). Since PTS did not incorporate any component to teach problem-solving procedure and it only emphasized on understanding conceptually at the microscopic levels and the relationship between symbolic and microscopic levels, the students might not be able to apply the problem solving skills required to solve the problems.

## Implications for teaching Chemistry

It is apparent, from the findings obtained in this study, that the students made more sense of the chemical symbols used to construct balanced chemical equations as they learned through studying the particles' behaviours and arrangements in the chemical reactions. They were able to gain conceptual understanding of the symbolic chemical equations as a representation of chemical reaction at the microscopic level. Nelson (2002) proposed the idea of teaching chemistry in a progressive manner. That is, teaching chemistry should start with observation at the macroscopic level before proceeding to interpret the observation at the microscopic level. He argues that if teachers teach only at the symbolic level, then students' interest in learning may suffer if they are not ready for the abstract level. Hence, in order to sustain students' interest and to improve their learning of chemistry, chemistry educators and teachers need to take note of the following during the instruction: (i) begin with some examples which are familiar to the students, (ii) gradually bring students through from the macroscopic level to the microscopic and symbolic levels, and (iii) explicitly make the connections between the levels where possible.

As such, this has implications for teaching Chemistry in schools. Teachers' readiness and willingness to incorporate the three levels of chemistry in their teaching is an area for consideration. This would mean that teachers have to look for suitable worksheets and teaching resources which can facilitate students' learning on chemistry at the symbolic, microscopic and macroscopic levels. Time is also another area of consideration. Will there be sufficient curriculum time available to implement teaching strategy which incorporates these three levels of chemistry? In order to reap the positive benefit, the students must be given sufficient amount of time to allow them to understand chemistry at the three levels as well as making connections between the levels in their learning processes. Hence, school administrators and teachers will have to look into their curriculum planning to cater for this need.

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