CHEMICAL REACTION: DIAGNOSIS AND TOWARDS REMEDY OF MISCONCEPTIONS

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ABSTRACT

Experience and literature show that most high school students do not have the correct mental models of coefficients and subscripts in chemical reactions. To contribute towards the conceptual reconstruction of scientific mental models of coefficients and subscripts in a chemical reaction a new teaching-learning strategy is suggested: Tetrahedral - in - Zone of Proximal Development (T-ZPD). This T-ZPD instructional strategy was introduced in an experimental group and compared with the traditional (conventional) approach as a control group on the effects of students' misconceptions and conceptual reconstruction of chemical reactions. The study has been conducted in high school chemistry classes in Addis Ababa, Ethiopia; the participants of the main study included a total of 160 students. The Chemical Reaction - Concept Inventory was administered to both groups as pre and post tests followed by interviews with selected students. The results of the independent t-test on students' post test scores on the concept inventory of chemical reaction show that the T-ZPD group students' conceptual reconstruction towards the scientific concept is statistically significantly better compared to the Traditional group students. [*AJCE, 1(1), January 2011*]

BACKGROUND

A. Misconceptions (Alternative Conceptions):

The chemical equation is a language of chemistry, one that chemists and chemical educators use constantly. Once chemical equations have been introduced in a course of study, it is often assumed that students understand this representational system. But many of the difficulties in learning chemistry are related to chemical equations (1). If students do not understand the language used by the instructor, how can they be expected to understand what is said?

In balancing equations, it is important to understand the difference between a coefficient of a formula and a subscript in a formula. The coefficients in a balanced chemical equation can be interpreted both as the relative number of molecules, moles or formula units involved in the reaction. And subscripts on the other hand indicate the relative number of atoms in a chemical formula. Subscripts should never be changed in balancing an equation, because changing subscript changes the identity of the substance. In contrast, changing a coefficient in a formula changes only the amount and not the identity of the substance and hence can be manipulated in balancing chemical equations. Balancing equation go further than word equation. It gives the formula of the reactants and products and shows the relative number of particles of each of the reactant and the products. Notice that the atoms have been reorganized. It is also important to recognize that in a chemical reaction, atoms are neither created nor destroyed. In other words, there must be the same number of each type of atom on the product side and on the reactant side of the arrow. Thus, a chemical equation should obey the law of conservation of mass.

Previous studies (2; 3) have shown that students can produce correct answers to various kinds of problems, including those involving chemical reactions, but their understanding of the underlying chemical concepts was lacking. It appears that often students' school learning is like a veneer—on the surface they are able to perform the required operations, but there is little depth of understanding (4).

Yarroch (5) found that of the 14 high school students whom he interviewed, only half were able to represent the correct linkages of atoms in molecules successfully (using circles representing atoms). Although the unsuccessful students were able to draw diagrams with the correct number of particles, they seemed unable to use the information contained in the coefficients and subscripts to construct the individual molecules. For example, in the equation, $N_2 + 3H_2 \rightarrow 2NH_3$, (Where ○ is Hydrogen Atom) students represented $3H_2$ as ○ ○ ○ ○ ○ ○ rather than ○○ ○○ ○○ . Students were able to use formulas in equations and even balance equations correctly without understanding the meaning of the formula in terms of particles that the symbols represent. These students had an additive view of chemical reactions rather than an interactive one

Another researcher Nakhleh (6) concluded that many students perceive the balancing of equations as a strictly algorithmic (plug-and-chug). Further, Yarroch (5) illustrates students' lack of understanding of the purpose of coefficients and subscripts in formulas and balanced equations of the reaction between nitrogen and hydrogen molecules as follows:

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

□□ ○○○○○○ □□○○○○○○

Ben-Zvi, Eylon, and Silberstein (7) concluded that balancing and interpreting equations for students is a difficult task. As an example, they performed a task analysis on the combustion of hydrogen molecules, as represented by the equation

$$2H_2(g) + O_2\,(g) \longrightarrow 2H_2O(g)$$

Ben-Zvi and his colleagues (7) argued that in order to appropriately interpret such equation the learner should understand many things such as, the structure and physical state of the reactants and products, the dynamic nature of the particle interactions, the quantitative relationships among the particles, and the large numbers of particles involved. Further they also note that some students seem to have an additive model of reaction: compounds are viewed as being formed by simply sticking fragments together, rather than as being created by the breaking and reforming of bond. For example, when H_2 reacts with O_2, the H_2 adds to the O_2. Bond breaking in H_2 and/or O_2 does not occur. Still on a similar research conducted by Sawery (8) on stoichiometry revealed that only about 10 percent out of 323 students could answer conceptual questions.

B. Conceptual Change Approaches

1. **Approaches from Pedagogy and Psychology**

According to one traditional view as reviewed by Lee et al (9), learning science involves the mastery of two independent components: content knowledge and science process skills. Based on this view, new knowledge (content) generated by the scientific method (process) is simply added to current knowledge. In contrast, the other view of learning science sees students taking an active role in building their own knowledge by modifying their existing conceptions through the process of conceptual change (10). This view is usually called constructivist view.

Conceptual change approaches: dissatisfaction – intelligible – plausible – fruitful

The best-known conceptual change model has been that of Posner et al. [10]; and Nussbaum and Novick (11) which describes the conditions of conceptual change. In this model, there are four steps: (i) learners must become dissatisfied with their existing conceptions; (ii) the new conception must be intelligible; (iii) the new conception must be plausible; and (iv) the new conception must be fruitful. After these conditions have been met, students can experience conceptual change.

1.2 Conceptual Reconstruction in Zone of Proximal Development (ZPD)

What is the Zone of Proximal Development (ZPD)? "Proximal" simply means "next". In this perspective (12), saw learning and development as neither a single process nor as independent processes. Central to Vygotsky's theory is his belief that biological and cultural development do not occur in isolation (13).

In explaining the concept of ZPD Vygotsky (14), stated “It is the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers”. Other authors defined as “Distance between what we know and our potential for knowing” (15). Applying the ZPD to science education “The degree to which the child masters everyday concepts shows his actual level of development, and the degree to which he has acquired scientific concepts shows the ZPD.” (Leontiev cited in 16).

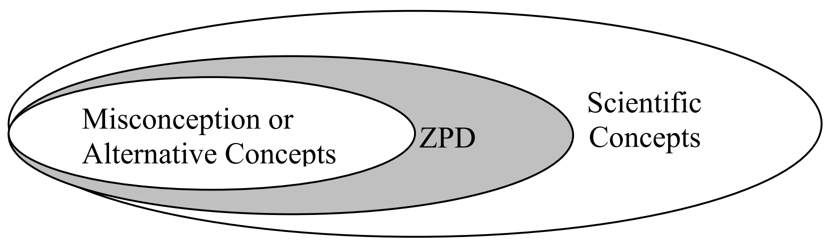


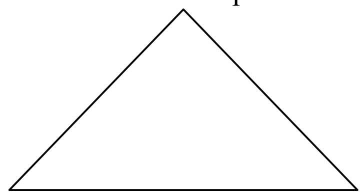
Figure1: Applying ZPD (Zone of Proximal Development) to science education

2. Approaches from Chemistry Education

2.1 Johnstone´s Trigonal Approach

One of the most cited chemistry education approaches is proposed by Johnstone (17; 18; 19; 20). In explaining the nature of chemistry or its anatomy he stated “I believe that chemistry exists in three forms which can be thought of as corners of a triangle. No one form is superior to another, but each one complements the other. These forms of the subject are (a) the macro and tangible: what can be seen, touched and smelt; (b) the submicro: atoms, molecules, ions and structures; and (c) the representational: symbols, formulae, equations, molarity, mathematical manipulation and graphs.” He further noted that “On the macro level, chemistry is what you do in the laboratory or in the kitchen or the hobby club. This is the experiential situation to which we are accustomed in most aspects of life. But chemistry, to be more fully understood, has to move to the submicro situation where the behaviour of substances is interpreted in terms of the unseen and molecular and recorded in some representational language and notation."

Macroscopic



Submicroscopic Representational

Figure 2: Johnstone´s Trigonal Approach

2.2 Barke and Engida´s Structural Oriented Approach

"Teaching-learning chemistry means discussing substances, their properties and reactions on the macro-phenomena level; and structural images and chemical symbols at sub-microscopic level. Structural models (images) could even be regarded as mediators between macro phenomena and chemical symbols - to avoid the predominance ´on the most abstract level, the symbolic level´"(21).

These researchers further explained the terms: "Phenomena: Investigating phenomena in nature or in the laboratory, showing substances and their properties, conducting experiments to show chemical reactions, offering students their own experiences by doing laboratory exercises. Structural Imagination: Taking structural models to show the structure of the substances involved before and after reactions, offering students the opportunity to built their own experiences, by building structural models, developing structural images, and by handling these models. Chemical Symbols: Deriving formulas from demonstrated or self-built models, in order to give students the idea that formulas are shorthand forms of structural models or of building units of the structure of molecules or unit cells."

These researchers after conducting empirical research on spatial ability in different cultures they recommend that the structural image, should be a mediator between the macro-phenomena and chemical symbols.

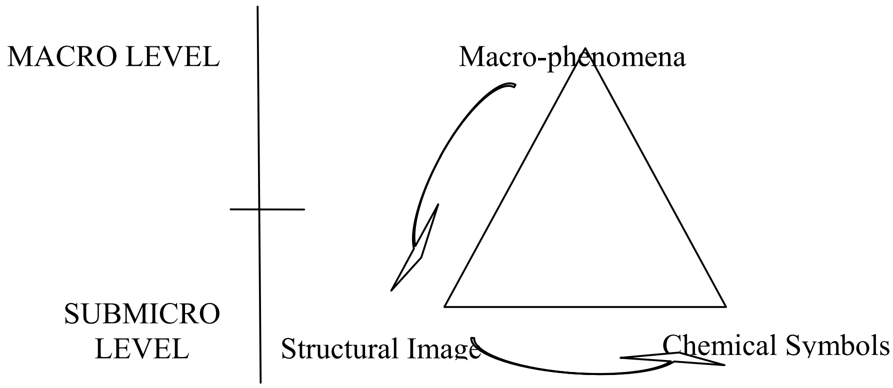


Figure 3: Barke and Engida´s Structural Oriented Approach

2.3 Mahaffy´s Tetrahedral Approach

Mahaffy (22) came up with different anatomy rehybridizing the Triangular Approach of Johnston with the Human Element and formulated a three dimensional Tetrahedral Chemistry Education Approach. This very powerful 3D- Tetrahedral Chemistry Education Approach has four vertices namely Macroscopic, Molecular, Representational, and Human-element. Where the Human-element represents two dimensions of learning chemistry: the human learner and the rich web of context.

Mahaffy described his approach of chemistry education emphasizing the human element as: Tetrahedral chemistry education could serve as an apt appraoch for describing what we value in chemistry education, highlighting the human element by placing new emphasis on two dimensions of learning chemistry: (i) The rich web of economic, political, environmental, social, historical and philosophical considerations, woven into our understanding of the chemical concepts, reactions, and processes that we teach our students and the general public. (ii) The human learner. Tetrahedral chemistry education emphasizes case studies, investigative projects, problem solving strategies, active learning, and matching pedagogical strategies to the learning styles of students. It maps pedagogical strategies for introducing the chemical world at the symbolic, macroscopic, and molecular level, onto knowledge of student conceptions and misconceptions (22; 23).

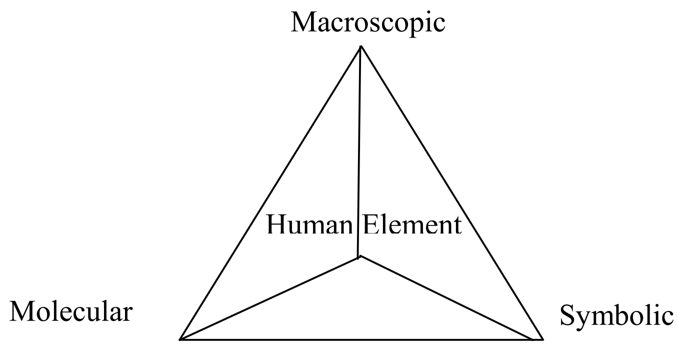


Figure 4: Mahaffy´s Tetrahedral Approach

One of the major innovations of the tetrahedral approach is the inclusion of context. In the following paragraphs attempt is made as to how context is treated and approached by different researchers and educators.

2.4 Yitbarek's Tetrahedral-in-ZPD (T-ZPD) Chemistry Education Approach

After critically reviewing the major approaches Yitbarek (24) forwards the following questions: 'where did the research findings of misconceptions go?", "Where did the teacher go?"; "Which theories are driving?; "what are the specific roles of the teacher, students and peers?"; "How are the chemistry and education be integrated in chemistry - education?", To answer these questions a more refined approach was proposed. This approach rehybridizes further 'Tetrahedral Chemistry Education' and 'Zone of Proximal Development (ZPD)', and we named it 'Tetrahedral - in - ZPD Chemistry Education Approach, and the details of it will follow.

The fundamental knowledge basis of this approach are: (i) Content knowledge refers to one's understanding of the subject matter- at macro-micro-symbolic representations; (ii) pedagogical knowledge refers to one's understanding of teaching-learning processes in the context of ZPD and knowledge of instructional media; (iii) contextual knowledge refers to establishing the subject matter within significant societaltechnological-political issues; (iv) research knowledge refers to knowledge of 'what is learned by student?', that is, findings and recommendations of the alternative conceptions research of particular topic in chemistry; and (v) pedagogy-content-context-research knowledge (PCCRK) refers to the integrated four knowledge areas. Thus, this approach incorporates and integrates five knowledge areas namely pedagogy, content, context, research, and PCCRK.

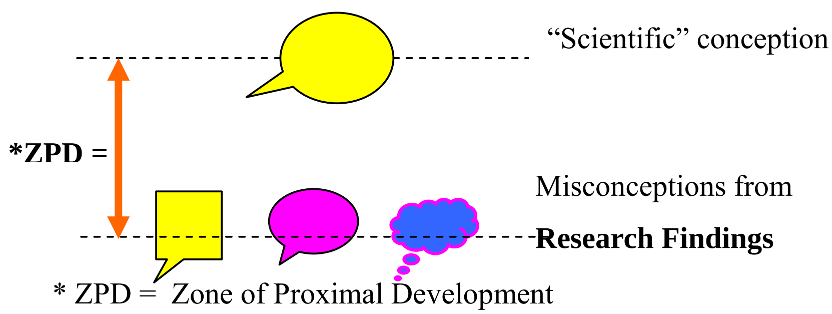
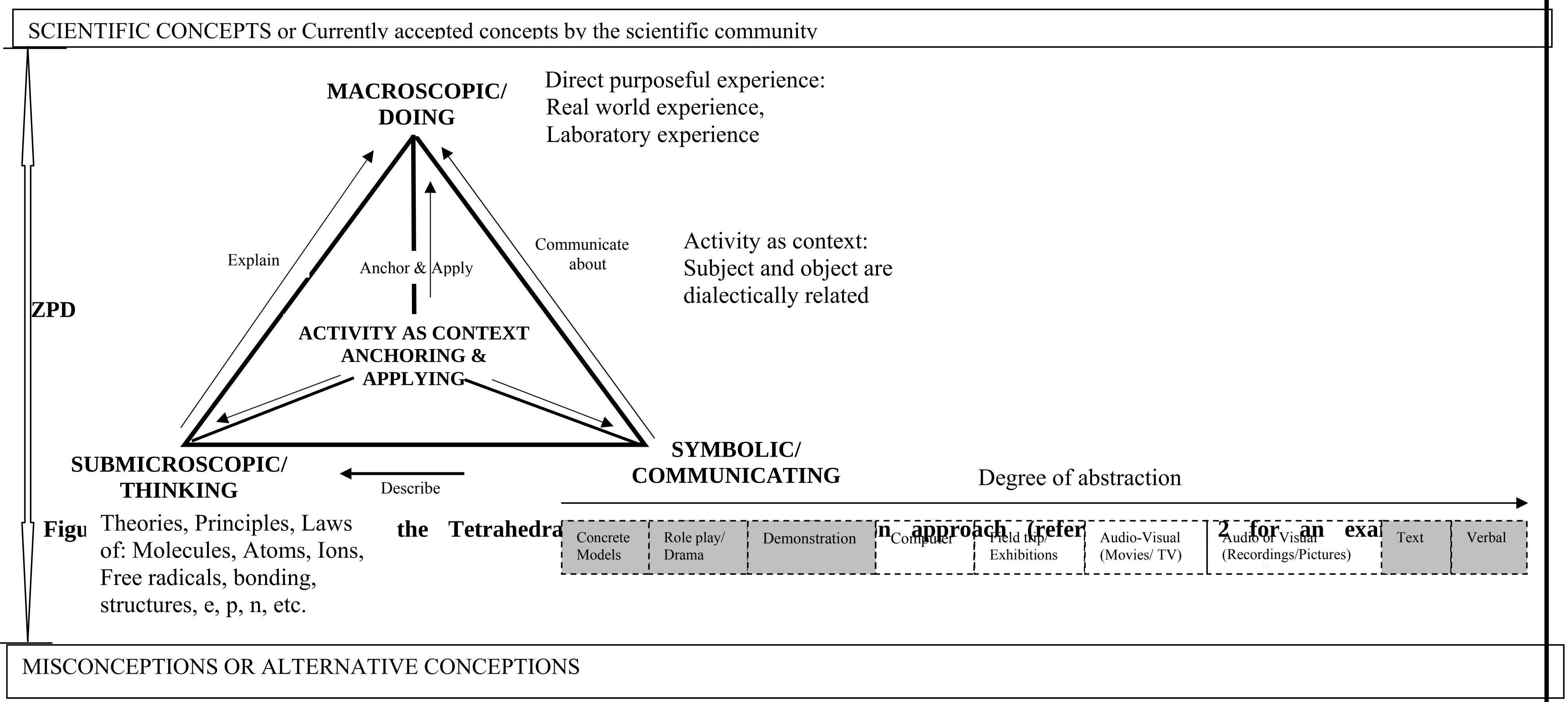


Figure 5: Concept cartoon as a strategy to incorporate research findings

Tetrahedral in ZPD Chemistry Education Approach (24)



Figu … the Tetrahedra … n approach (refer … 2 for an exa…

Unique Features of the Tetrahedral-in- ZPD (T-ZPD) Approach (24)

- Simultaneous Chemical Representation in T-ZPD
- Incorporating Chemistry Misconceptions Research Knowledge in T-ZPD
- Integrates Pedagogical - Content - Context - Research Knowledge and help teachers to practice what is expected from them in actual classroom (PCCRK)
- The learner and the teacher or more knowledgeable others (MKO) in Tetrahedral-in-ZPD
- Contextual Knowledge in T-ZPD
- Symbolic representations at different levels of instruction

STATEMENT OF THE PROBLEM

Equations are essential tools to communicate chemical reactions at macroscopic, submicroscopic and representational levels of understanding chemistry. Teachers usually assume that students who can balance a chemical equation understand the chemical concepts that the equation represent. Most students however balance chemical equations algorithmically not conceptually.

PURPOSE OF THE STUDY

The major purpose of this study is to evaluate students' conceptual reconstruction of the conceptions of coefficients and subscripts in a balanced chemical equation using the Tetrahedral-in- ZPD approach.

RESEARCH QUESTIONS

To attain the above major research purpose the following research question was specifically addressed: How do experimental (T-ZPD) and control group (traditional) students compare in conceptual reconstruction of coefficients and subscripts in a chemical reaction before and after instruction?

PARTICIPANTS

The participants for this study were grade 10 students from two government schools in Addis Ababa, Ethiopia. Two equivalent classes were chosen as the experimental and control groups, based on the results from the pretests. The sample consisted of 84 students (average age 16.37 years) in control group and 80 students (average age 16.54 years) in experimental group; which make a total of 164 students.

INSTRUMENTS

Two- tiered questions were used for the pretest and post test conceptual inventory of coefficients and subscripts in a chemical reaction. Note that those students whose response is correct to both tiers considered to have the correct basic conceptions of coefficients and subscripts. Students who respond to the first tier correctly but could not answer or draw in the second tier are considered as having misconceptions. And if students' responses to both questions are incorrect or for the first question correct but for the second tier incorrect they are considered as students with "no understanding".

Table 1: Categories: correct conception, misconception and no-understanding

Question in pretest or posttest		**Category**
Tier 1	**Tier 2**	**Students have:**
Correct	Correct	Correct conception
Correct	Incorrect	Misconception
Incorrect	Incorrect	No- understanding
Incorrect	Correct	

RESULTS

The pretest was administered to both the experimental and control group students before the instruction. There was no statistically significant pre test mean difference found between the experimental group (M =.2075, SD = .40943) and control group (M = .1667, SD = .37582) with t = .553, df = 111, p > 0.05 (Table 2). The result indicates that students in the experimental and control groups were similar in respect to representing the chemical reaction at the submicroscopic level.

Table 2: Group Statistics and Independent Samples Test

		Pretest					Posttest				
Question type	Group	N	M	S.D.	t (df)	p	N	M	S.D.	t (df)	p
(i) Balancing	Control	81	.7407	.44096	.726 (156)	.469	84	.7857	.41279	-.843 (162)	.400
	Experimental	77	.6883	.46622			80	.8375	.37124		
If the equation was correctly balanced:											
(ii) Representing the balanced equation using diagrams	Control	60	.1667	.37582	-.553 (111)	.581	66	.1667	.37553	-4.034 (131)	.000
	Experimental	53	.2075	.40943			67	.4776	.50327		

*p < .001

As there were no significant differences between the pre-test scores of the experimental and the control groups, the post-tests scores of the groups were compared using an independent *t*-test. The data showed that there was a statistically highly significant difference in post test scores of the experimental group (M =.4776, SD =.50327) compared to the control group (M = .1667, SD = .37553) t= -4.034, df =131, $p < .001$ (Table 2 and figure 7).

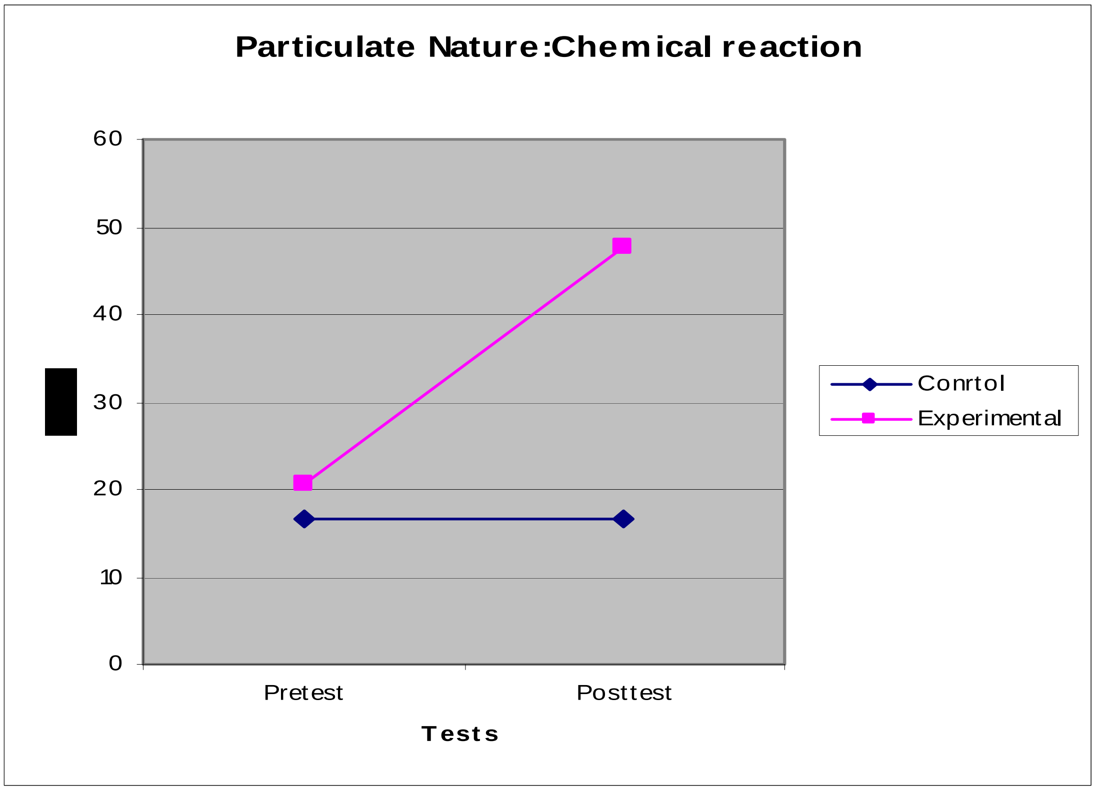


Figure 7: Mean percentage for pre and post tests

RECOMMENDATIONS

Curriculum

The teaching material should be written taking in to account the four major dimensions of the Tetrahedral-in-ZPD chemistry education approach namely: Context, Submicroscopic, Submicroscopic, and Symbolic. (See appendix 2 for details).

Instruction

Instruction should be in the frame work of the Zone of Proximal Development (ZPD). In addition it should use a variety of symbolic representations. In this study from the range of symbolic representations the non-technological tools namely: Molecular models, role play and concept cartoons were found to help students understand and distinguish coefficients and subscripts. Hence it is recommended that during instruction emphasis should be given to molecular models, role play and concept cartoons (refer Appendix 2).

Assessment

Instead of only asking students to balance a chemical reaction, it is recommended to use a two-tier question. Where the first question is simply to balance algorithmically and the second question that follow tries to ask whether the students have the mental image of what they were balancing. Examples follow:

Example 1:

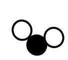
Tier 1:

Balance the following reaction: $H_2 + O_2 \longrightarrow H_2O$

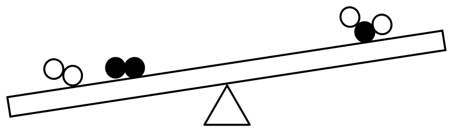
Tier 2:

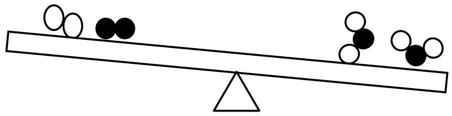
Looking carefully at the drawings below write their appropriate chemical reactions on the space provided.

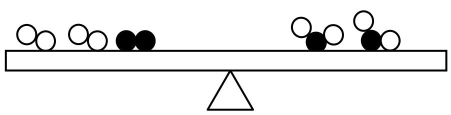
Let:

 = Hydrogen molecule,  = Oxygen molecule,  = Water Molecule

Drawing: Chemical reaction:

1.  = $H_2 + O_2 \longrightarrow H_2O$

2.  = ____________________

3.  = ____________________

Example 2:

Tier 1:

Balance the following reaction: $N_2 + H_2 \longrightarrow NH_3$

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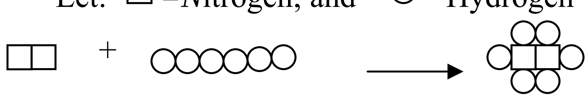
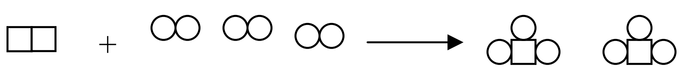
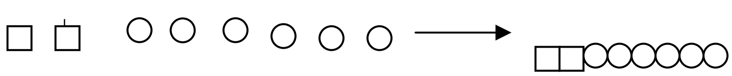
Tier 2:

Which of the following pictorially represent the above balanced chemical equation?

Let: □ =*N*itrogen; and ○= Hydrogen

(a) 

(b) 

(c) 

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Appendix 1
Example: pretest and posttest

Pretest:

Tier (i) Balance the following chemical reaction:

$$H_2 + O_2 \longrightarrow H_2O$$

____

Tier (ii) Let: □ = Hydrogen atom, and ○ = Oxygen atom

Using the above notations represent pictorially your balanced chemical reaction.

__________________ + _______________ ⟶ _______________________

Posttest:

Tier (i) Balance the following chemical reaction:

$$N_2 + H_2 \longrightarrow NH_3$$

____

Tier (ii) Let: □ =*N*itrogen atom ; and ● = Hydrogen atom

Using the above notations represent pictorially your balanced chemical reaction.

__________________ + _______________ ⟶ _______________________

Appendix 2: Reaction of carbon atoms and Oxygen molecules
Context

Carbon dioxide is one component found in air with very low percentage (0.03%). If carbon dioxide is available in a given sample of air exceeds this limit, we say the air is polluted. Let us now study the reaction between Carbon atoms in wood and Oxygen molecules in Air.
What do you observe during Meskel (the finding of the True Cross) Celebration when a large controlled fire, or *Demera*, is burning? (Hint: Light, heat, smoke…..)

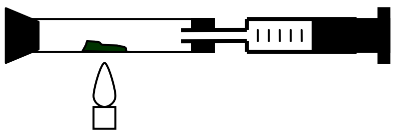
- How is burning of wood a potential 'source' of polluting air.

Macroscopic

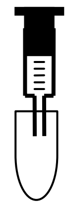
- All chemical reactions must involve detectable change
- A chemical reaction involves a change from reactant substances to product substances, and the product substances will have physical and chemical properties different from those of reactants.

Look carefully at the burning of carbon atoms in air. What do you think the air component responsible for burning? (Yes Oxygen molecules, about 20% of air).

Burning carbon atoms in air



Testing for Carbon Dioxide molecules using Barium hydroxide solution



What do you think the gas collected at the syringe? Test using Barium Hydroxide solution (Baryta water), and write your observation.

Submicroscopic

- Chemical reaction is a process of bond breaking and bond making involving many particles.
- Chemical reaction is not an additive but it is an interactive process.

Representational

Activity 1 Molecular Models

Using the structural models construct a model that shows the reaction between carbon and oxygen to produce carbon dioxide. Display the model of atoms and molecules before and after reaction.

Write the balanced chemical reaction between carbon and oxygen based on the molecular model.

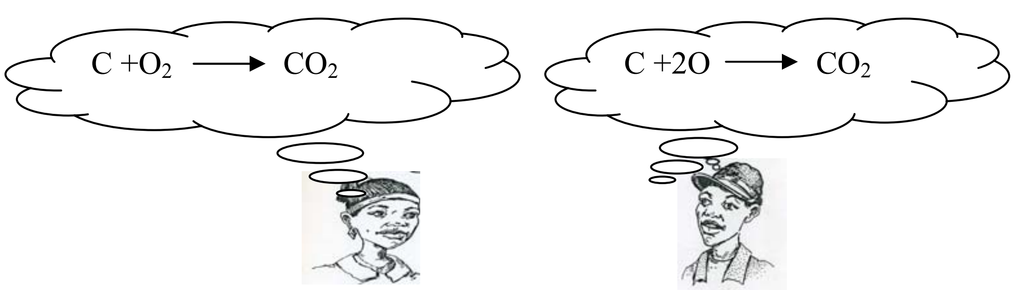
Activity 2 Role Play

Let five students write C- in paper, hold and stand in front of the class. Let five-pair students representing oxygen be in front and role play the reaction between carbon and oxygen to form carbon dioxide.

Write the balanced chemical reaction between carbon and oxygen based on the role-play.

Activity 3 Concept Cartoon

Carbon atoms burn in air to produce carbon dioxide molecules. Write the balanced chemical reaction. Aster and Abebe are suggesting the following equation, who do you thing is right?



Aster Abebe

What do you think?