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Towards a Framework for Science Education in Ethiopia

By

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Abstract

For almost a decade, a series of studies were conducted in science education in Ethiopia on alternative conceptions (misconceptions), the root causes of these misconceptions and, finally, their possible remedies. The purposes of these studies were to identify and to determine the extent of the alternative conceptions held by students, to analyze the possible root causes and to come up with possible strategies for conceptual change. The methodologies followed in these series of studies were descriptive, followed by explanatory and, finally, experimental phase. The subjects of the study were drawn from primary, secondary and college students of Addis Ababa. The results of these series of studies indicated that students not only have many misconceptions on the basic concepts of chemistry but also these conceptions did not reduce statistically as grade levels increase. Regarding the root causes of students' misconceptions, lack of practical activities and teachers themselves were found to be the major reasons. Finally, being aware of the misconceptions and the root causes, an experimental study was conducted which compared the traditional and a newly suggested conceptual change framework, namely, Tetrahedral-in-Zone of Proximal Development (T-ZPD). The results of the independent t-test on students' conceptual reconstruction towards the scientific concept of the T-ZPD group were statistically significantly and they were better compared to the traditional group students in all contexts investigated. As a component of this framework, low cost apparatus for practical activities were improvised and found to be very successful. Hence, in this paper, the T-ZPD framework was suggested as a potential curriculum, instruction and assessment framework for increasing the quality of science education at all levels in Ethiopia.

Background of the Study

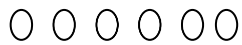
Misconceptions (Alternative Conceptions)

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. 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 as the relative number of molecules, moles or formula units involved in the reaction, while 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, but not the identity of the substance and, hence, can be manipulated in balancing chemical equations. Balancing equation goes 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, so the atoms have been reorganized. In fact, 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 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.

Yarroch (1985) found that out of the 14 high school students whom he had 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, $N_2 + 3H_2 = 2NH_3$, students represented $3H_2$

as 

rather than 

Moreover, students were able to use formulas in equations and even balance equations correctly without understanding of 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 (1992) concluded that many students had perceived the balancing of equations as a strictly algorithmic (plug-and-chug). Further, Yarroch (1985) illustrated 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 (1987) 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 in 1987 argued that in order to appropriately interpret such an equation the learner should understand many concepts, 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. They further 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 (1990) on stoichiometry revealed that only about 10 percent out of 323 students could have answered conceptual questions.

Conceptual Change Approaches

Approaches from Pedagogy and Psychology

According to one of the traditional views as reviewed by Lee et al. (1993), 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 as taking an active role in building their own knowledge by modifying their existing conceptions through the process of conceptual change. This view is usually called constructivist view.

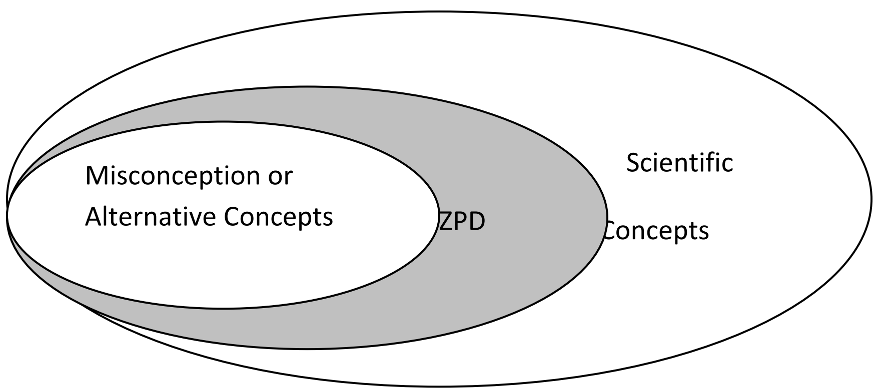
Conceptual Change Approaches: Dissatisfaction – intelligible – plausible – fruitful

The best-known conceptual change models have been that of Posner et al. 1982), which describes the conditions of conceptual change. In this model, there are four steps: (1) Learners must become dissatisfied with their existing conceptions; (2) The new conception must be intelligible; (3) The new conception must be plausible; and (4) The new conception must be fruitful. After these conditions have been met, students can experience conceptual change.

Conceptual Reconstruction in Zone of Proximal Development (ZPD)

What is the Zone of Proximal Development (ZPD)? "Proximal" simply means "next". In this perspective, learning and development are seen neither as a single process nor as an independent process. Further, central to Vygotsky's theory (1978) is his belief that biological and cultural developments do not occur in isolation. In explaining the concept of the ZPD, Vygotsky (1987) 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 ZPD as “Distance between what we know and our potential for knowing”. Applying the ZPD to science education, “It is 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).

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



Source: Designed by the author, 2011.

Approaches from Chemistry Education Johnstone´s Trigonal Approach

One of the most cited chemistry education approaches is proposed by Johnstone. 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 sub micro: atoms, molecules, ions and structures; and (c) the representational: symbols, formulae, equations, molarities, 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 sub micro situation where the behaviour of substances is interpreted in terms of the unseen and molecular and recorded in some representational language and notation."

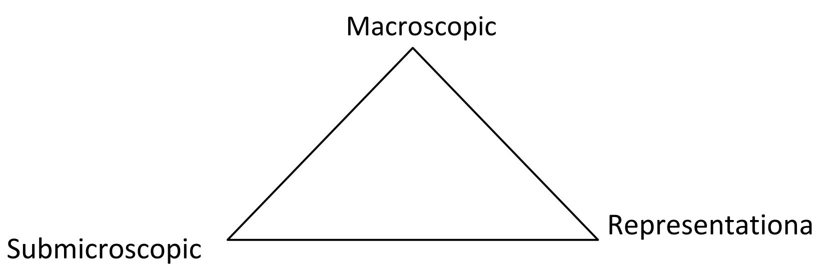


Figure 2: Johnstone´s Trigonal Approach

Source: Adopted from Johnstone, 1997 and 1999.

Barke and Engida´s Structural Oriented Approach

Barke and Engida (2001) stated:

> *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'.

These researchers further explained the following terms as follows:

> **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 build their own experiences, by building structural models, developing structural images, and by handling these models. **Chemical Symbols**: These are formulas deriving 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.

After above-stated these researchers had conducted empirical research on spatial ability in different cultures, they recommended that the structural image should be a mediator between the macro-phenomena and chemical symbols.

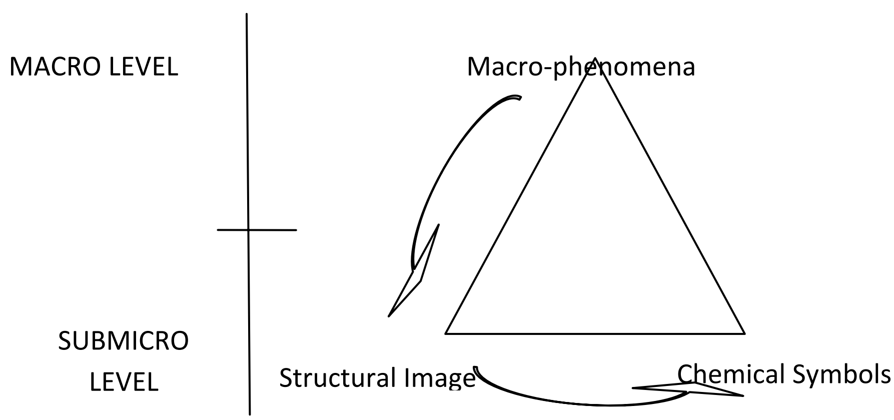


Figure 3 -- Barke and Engida´s Structural Oriented Approach

Source: Adopted from Barke and Engida, 2001.

Mahaffy´s Tetrahedral Approach

Mahaffy (2004) came up with different anatomy re-hybridizing 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 further described his approach of chemistry education by emphasizing the human element as: Tetrahedral chemistry education could serve as an apt approach for describing what we value in chemistry education, highlighting the human element by placing new emphasis on two dimensions of learning chemistry:

> *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.....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.*

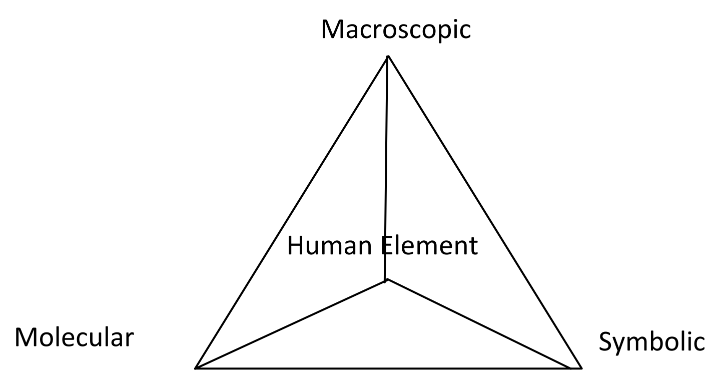


Figure 4 --Mahaffy´s Tetrahedral Approach

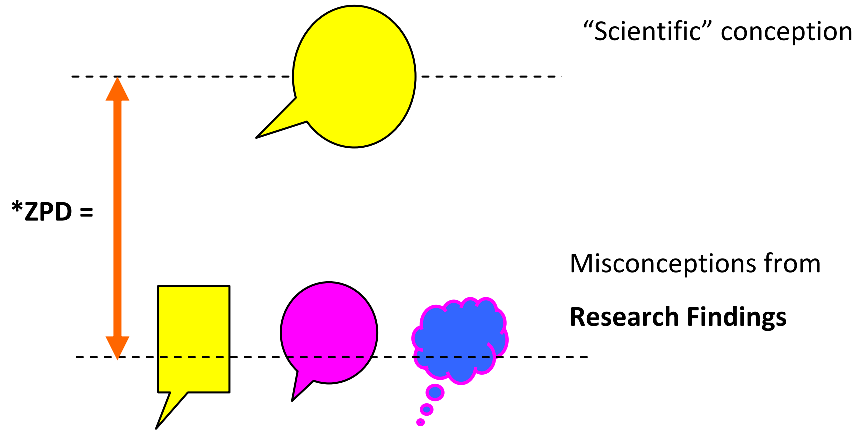
Source: Adopted from Mahaffy, 2006.

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.

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

Having critically reviewed the major Chemistry Education Approaches, Sileshi (2009) 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 the chemistry and education are to be integrated in chemistry - education?" To answer these questions, a more refined approach was proposed. This approach re-hybridizes 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 follow.

The fundamental knowledge basis of this Approach are: (1) Content knowledge refers to one's understanding of the subject matter at macro-micro-symbolic representations; (2) Pedagogical knowledge refers to one's understanding of teaching-learning processes in the context of ZPD and knowledge of instructional media; (3) Contextual knowledge refers to establishing the subject matter within significant societal-technological-political issues; (4) 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 (5) 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.

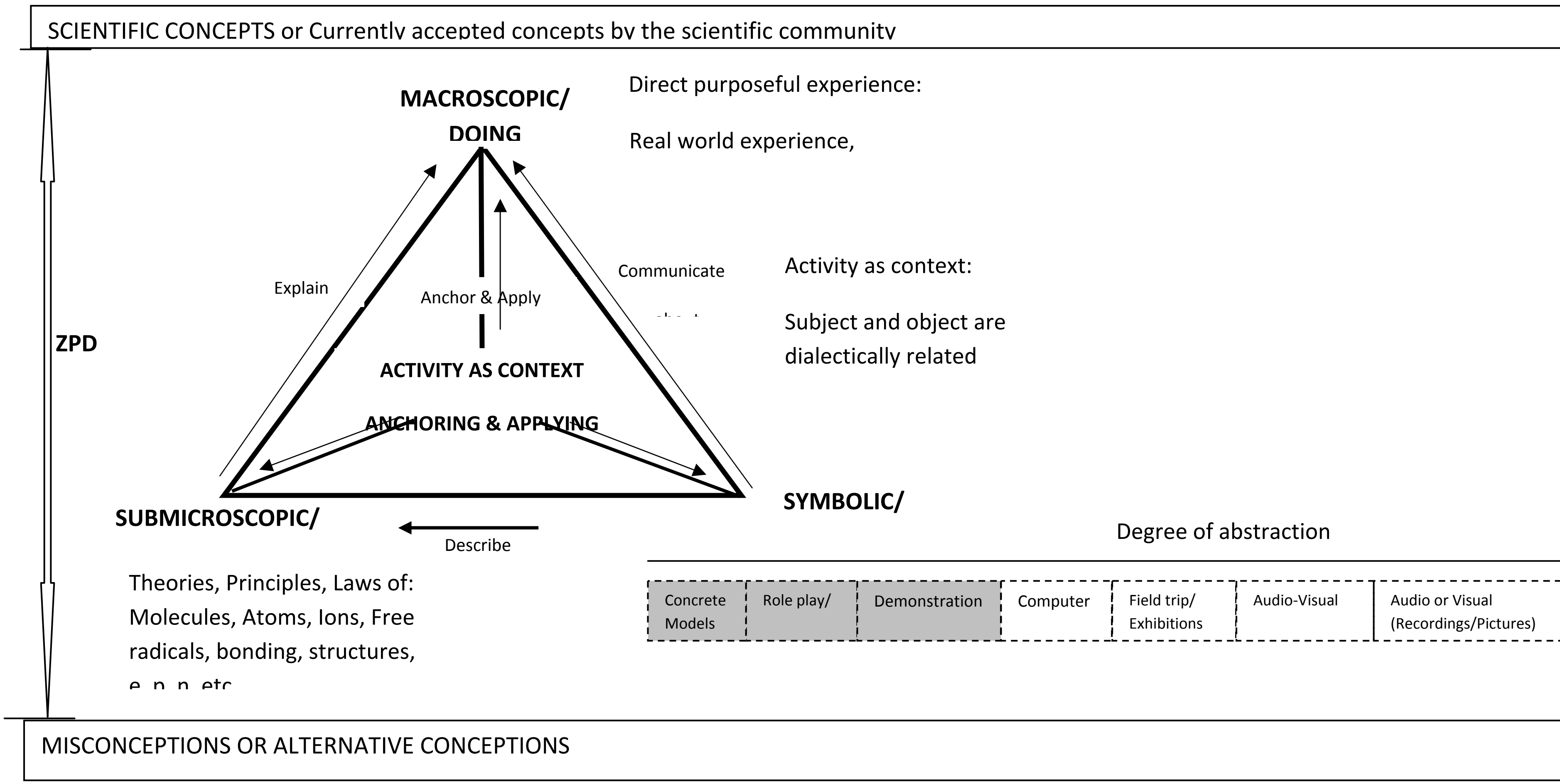


* ZPD = Zone of Proximal Development

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

Source: Sileshi, 2009.

Fig 6 -- Tetrahedral in ZPD Chemistry Education Approach



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

The Tetrahedral-in-ZPD (T-ZPD) Approach has the following features:

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

The status of Science Education in Ethiopia

Different studies conducted on science education found that the Ethiopian students' learning performance in mathematics and science were found to be still very low (JICA, 2002), even though the performance of mathematics and science had increased slightly with increase in grade levels (MoE, 2004 cited by Sileshi, 2009). Such results stress the importance of developing new approaches for increasing the students' performance level, following results from two test sample study on misconceptions and their possible causes.

Researches

Misconceptions Researches

Study 1: Survey of Chemistry Misconceptions (2003)

● Principal Investigators: Sileshi and Temechegn,

● Sample Size: 329 (Grade 10 =163; Grade 12=166), and the number of schools: 10 schools in Addis Ababa.

●Research Questions of this study were:

- ●What misconceptions do grade 10 and grade 12 students hold?
- ●To what extent, do the misconceptions differ from grade 10 to grade 12 students?
- ● Areas of research: Equation and Stoichiometry; Changes of state; Macro and micro-properties; Mole; Particulate nature of matter; Conservation of mass; and Gas.

Example 1. Equations and Stoichiometry

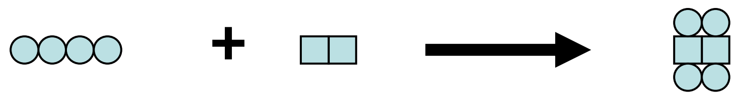
(i) Balance the following reaction:

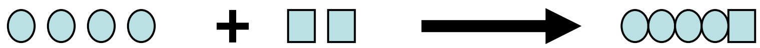
$$H2 + O2 = H2O$$

____

(ii) Which of the following pictorially represent(s) the above-balanced chemical equation?

Let: = Hydrogen atom; and *Oxygen* atom

a 

b 

c 

d 

e. All of the above are correct

Results

Table 1- Distribution of responses to the questions

	Question 1: **Traditional** (N=38) "f" and "%" students answers to traditional questions		Question 2: **Conceptual** (N=33) "f" and "%" of students choosing particular answers to conceptual question out of those who correctly answered the traditional question			
	Correct	Incorrect	Correct	Incorrect		
Gas Law	C	(a,b,d)	a	b (3)	c (15)	d(3)
f (%)	33 (87%)	5(13%)	12(36%)	21 (64%)		

Source: Computed by the researcher, 2011.

Comparison

t321 = -4.185, $p < 0.000$; statistically significant difference at .05 level.

Example 2. Changes of States

Q1. Assume a beaker of pure water has been evaporated completely in a closed container. What is the composition of the water vapor?

(a) Air.

(b) Oxygen gas and hydrogen gas.

(c) Water.

(d) Water, hydrogen and oxygen.

(e) Heat.

Table 2 - Percentage distribution

(Q#)	N		a (%)		B (%)		C (%)		c (%)		e (%)	
	Grade		Grade		Grade		Grade		Grade		Grade	
	10	*12*	10	*12*	10	*12*	10	*12*	10	*12*	10	*12*
Q# **1**	163	*165*	15.3	*4.2*	44.2	*57.0*	**11.0**	**15.2**	22.7	*17.0*	6.7	*6.7*

Source: Calculated by the author, 2011.

Comparison

t326 = -1.101, $p < 0.272$; not statistically significant difference at .05 level.

Table 3 - Response comparison for question #1 of the present study with other studies

Alternative Conceptions **(Responses)**	Comparison-1		Comparison-2	
	Osborne and Cosgrove (1983) Late high school (Age16)	**Present Study** 10^{th} grade (Age~16)	**Mulford** First year college(1996) (Age~17)	**Present Study** 12^{th} grade (Age~17)
Air	~27%	15.3%	5%	*4.2%*
Oxygen gas and hydrogen gas	~45%	66.9% (44.2+22.7)	55% (43% + 12%)	*74.0% (57.0+17.0)*
Steam (Water or Water vapor)	*~27%*	*11.0%*	*38%*	*15.2%*
Heat	~1%	6.7%	2%	*6.7%*

Shaded = currently accepted by the scientific community.

Source: computed by the researcher, 2011.

Table 4 – Summary of the Study Findings

Grade 10	Grade 12	Remark
79 %	**58 %**	Can't differentiate subscripts and coefficients, and has an additive view of a chemical reaction.
70 %	**74 %**	Believe that water breaks into its component during evaporation.
66 %	**56 %**	Believe matter is continuous.
80 %	**70 %**	Can't distinguish between the properties of a single atom of copper and a copper wire.
73 %	**75 %**	Wrongly conserve number of moles and number of molecules during chemical reaction.

54 %	**42 %**	Can't conserve mass during solution formation.
73 %	**59 %**	Students can't associate the mole exclusively with the number of particles.
75 %	**65 %**	Believe that gases contracted on cooling.
55%	**36 %**	Believe that gases are weightless.

Source: Compiled by the author, 2010.

Conclusions

1. The study indicated that a significant proportions (>50%) of both G10 and G12 students do not master the basic chemical concepts or have misconceptions about.
2. Comparison: G12 student's difference is not significant in majority of the concepts compared to G10. In the present study, correct concepts are low compared to other studies.

Study 2: Conceptual Vs. Traditional Questions (2005)

Purpose: To compare achievement on the Traditional Vs. Conceptual questions.
Area of Study: Stoichiometry and Gas Law

Instruments: Two-tiered Questions (Traditional versus Conceptual Questions)

Subjects: First year students of Natural Science Stream, KCTE.

Sample size: 38 out of 96 students.

Sampling: Simple Random Sampling (SRS).
Test: Two-tiered questionnaire.

Example: Gas Law

Question 1: (Traditional)

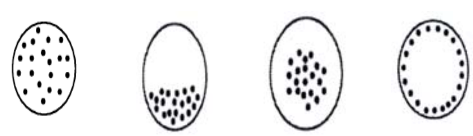
A given mass of gas occupies 5L at pressure of 0.5atm and 50 K. Calculate the pressure of the gas if it is cooled to 10K at constant volume.

a. 2.5 atm   b. 0.5 atm   c.0.1 atm   d. None

Questions 2: (Conceptual)

The following diagram represents a cross-section area of a 5L steel tank filled with hydrogen (H2) gas at 50K and 0.5 atm pressure (the dots represent the distribution of H2 molecules).

If the tanker is cooled to 10 K, which of the following diagrams illustrate (show) the distribution of Hydrogen (H2) molecules, assuming there is no change in state.



(a)   (b)   (c)   (d)

Table 5 - Frequency and percent responses for Traditional and Conceptual gas question

	Question 1: **Traditional** (N=38) "f" and "%" students answers to traditional questions		Question 2: **Conceptual** (N=33) "f" and "%" of students choosing particular answers to conceptual question out of those who correctly answered the traditional question			
	Correct	Incorrect	Correct	Incorrect		
Gas Law	C	(a,b,d)	a	b (3)	c (15)	d(3)
f (%)	33 (87%)	5(13%)	12(36%)	21 (64%)		

Source: Computed by the researcher, 2011.

General Conclusions

- Only about one-fourth of the respondents correctly conceive the concepts.
- Computed (X2 = 26.57) > Critical value (x2 = 6.64) at <0.01 and df=1.
- Success= Traditional > Conceptual approach.

Study 3: Alternative Conceptions of Chemical Concepts of the First and the Third Year Chemistry Degree Students at KCTE (2011).

Participants: First Year (95) students (whose average age was 21.2 years) and third Year (69) students (average age=21.88 years). Both groups took chemistry as a separate subject since grade 7.

Research Questions of the study were:

. What types of alternative conceptions do first year and third year chemistry students hold?

. How do we compare the alternative conceptions between the first and the third year chemistry students?

Example: Solutions

Q9. Figure 1 represents a 1.0-L of sugar solution. The dots in the magnification circle represent the sugar molecules at a very small portion. In order to simplify the diagram, the water molecules have not been shown.

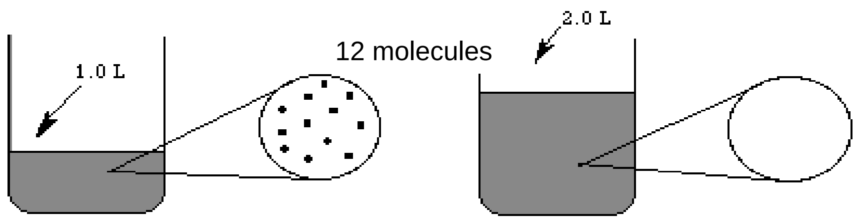
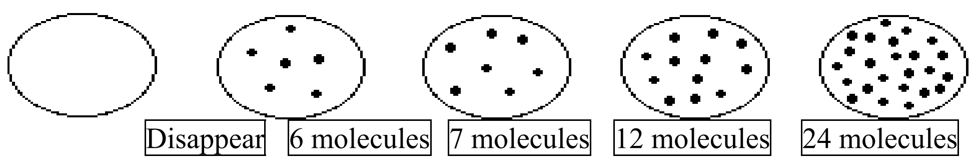


Figure 1 Figure 2

. Which response represents the view of the same portion after 1.0 L of water were added?



(a) (b) (c) (d) (e)

Table 6 - **Results of the above questions**

CCI	N		% Percent Alternative Conception									
			a		b		c		d		e	
	Level		Level		Level		Level		Level		Level	
	1st	*3rd*	1st	*3rd*	1st	*3rd*	1st	*3rd*	1st	*3rd*	1st	*3rd*
Q# 9	95	*69*	14.9	*22.1*	16.0	*10.3*	23.4	*35.3*	21.3	8.8	24.5	*23.5*

Source: Compiled by the author, 2011.

Comparison:

$t160 = -.153$, $p < 0.045$;

Statistically significant difference at .05 level.

Table 7 - Response comparison with other study

ALTERNATIVE CONCEPTION (Responses)*	Mulford's Study, (Australia)	Present Study 1st year (Ethiopia)
6 molecules-correct response	75%	*23%*

Source: Own study results, 2011.

Table 8 – Summary

1st Year	3rd year	Remark
75 %	64 %	Can't differentiate subscripts and coefficients, and has an additive view of a chemical reaction.
90 %	84%	Believe that water breaks into its component during evaporation.
87 %	83 %	Can't distinguish between the properties of a single atom of copper and a copper wire.
54 %	42 %	Can't conserve mass during solution formation.
76 %	65 %	Students doubled concentration of a solution when it is diluted by a factor of two.

Source: Summary of the researcher's findings, 2011.

Conclusions

1. The study indicated that the majority (>70%) of the first and the third year degree students do not master the basic chemical concepts at higher order thinking skills.
2. Comparison: The third year students' difference is not statistically significant in the majority of the concepts compared to the first year students.

Causes of Misconceptions

Students' textbooks are one of the major curriculum resources available to students, sometimes even the only one, especially in developing countries like Ethiopia. In this paper figures of Grade 7 Chemistry Text Book and Grade 8 students' drawings were analyzed in light of their symbolic representation of the particulate nature of matter. The analysis focused on figures where the textbook and students represented solids, liquids, and gaseous particles, focusing on the concept of the particulate nature of matter because it is very fundamental. Regarding this, some scholars say: "One of the central instructional goals of most junior high school science curricula is the understanding by students of the particle model of matter. For, in modern science, the fundamental notion that all matter is particulate and not continuous is of prime importance for all causal explanations of any kind of change in matter" (Nussbaum, 1982, p. 124) and the same author added: "the ability to represent matter at the particulate level is important in explaining chemical reactions, changes in state and the gas laws, stoichiometric relationships, and solution chemistry" (Gabel, Samuel and Hunn, 1987, p. 695).

Students' conceptions of the particulate nature of matter have been the subject of extensive research and findings from these studies lead to the view that particle ideas are poorly grasped, as even with prompting around 25% of students in mixed age categories used only continuous ideas of matter in their answers (Kind, 2004). Nakhleh (1992) reviewed the research in this area and commented that many students from all age groups had appeared to view matter as being made up of a continuous medium that is static and space filling. Students usually transfer macro properties to sub-microscopic particles, saying like: 'there are particles in the ice crystals, when the ice melts, these particles melt' (Barke, 2006).

Acknowledging the role of the students' textbooks in teaching and learning, both science education researchers and policy makers have called for systematic, research-based reviews of science curriculum materials as a means for improving their quality, influencing teacher practice, and supporting science education reform (Good, 1993).

Hence in this paper attempt is made to systematically study figures of a text book and its implication on students' conceptions.

The Purpose of the Study

The purpose of the study is to evaluate the figures of Grade 7 Chemistry Students' Textbook of Addis Ababa, Ethiopia. This study particularly focused on *symbolic representation* of the particulate nature of matter and its implication on students' conceptions.

Instrument for Figure Analysis

Gabel et al. (1987) devised a coding sheet called 'Nature of Matter Inventory'. The inventory contained guidelines for examining nine attributes that text book writer and students should have considered in drawing their diagrams, namely, particle discreteness, conservation of particles, proximity of particles, orderliness of particle arrangement, locations of particles in container, constancy of particle size and shape, chemical composition, arrangement of products and bonding. In this paper we will consider only the first six criteria.

Sources of data: (1) Figures of grade 7 Chemistry Student Text Book of Addis Ababa, published in 1997, revised and re-published in 2005 and reprinted in 2006.
Revision of the Text Book was conducted by the Curriculum Development and Research Department of the Education Bureau under auspices of the City Government of Addis Ababa.

All government schools utilize this chemistry text book at present time. a total of 181 Grade 8 students of the three government elementary schools were found to use drawings in Addis Ababa.

Text Book Analysis

Description of the Three States of Matter

The Grade 7 Chemistry Student's Textbook of Addis Ababa (Addis Ababa City Government Education Bureau, 2006, p. 8) under the subsection 'Physical states of substances' describes the three states of matter and the particles of the three states in terms of shape, size, orderliness, motion, vibration, and force of attraction. It describes solids as "A solid has s definite shape and volume. The particles in a solid are orderly arranged…." while liquid as 'A liquid has definite volume but not definite shape. This shows that particles in liquids are less ordered than solids. The particles of a liquid are fairly close to each other…' but gases are described as 'A gas has neither definite shape nor definite volume. The particles of a gas are very far apart from each other with out pattern. They are extremely disordered…." At the end of the description, this Chemistry student's Textbook invites readers to a figure that shows 'The arrangement of the particles of the three states of substances'.

Particulate Nature of Matter during Change of State

The textbook presents the arrangement of particles of the three states as shown in the figure below.

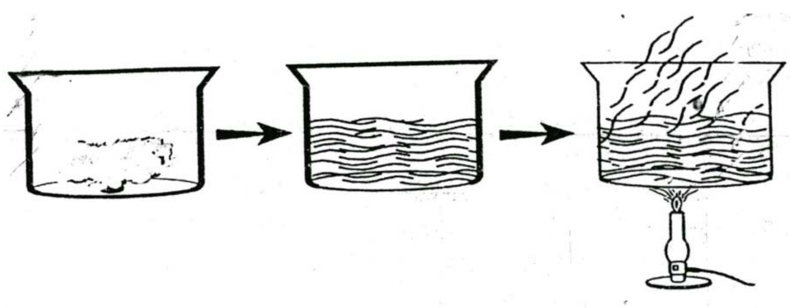


Figure 2.1The arrangement of the three states of substance

Source: adopted by the author, 20111.

Figure 1-- Scanned figure showing the arrangement of particles in the three states of matter during change of state (Addis Ababa City Government Education Bureau, 2006, p. 9).

In Figure 1 above, the solid particles are not visible and clear; liquids and gases are represented by curved lines as continuous. The Figure fails to represent and to convey information in reference to the criteria, namely, particle discreteness, conservation of particles, proximity of particles, constancy of particle size and shape, orderliness of particle arrangement, and locations of particles in a container. We concluded that this figure is completely inappropriate to represent the particles and the properties of solids, liquids and gases in that the Textbook describes totally reinforcing the belief of continuous nature of matter. This picture did not pay attention to the basic particle behaviour and characteristics.

In the subsequent section of the same Textbook under the subtitle "change of state", particles during changes of state of water were presented as shown below.

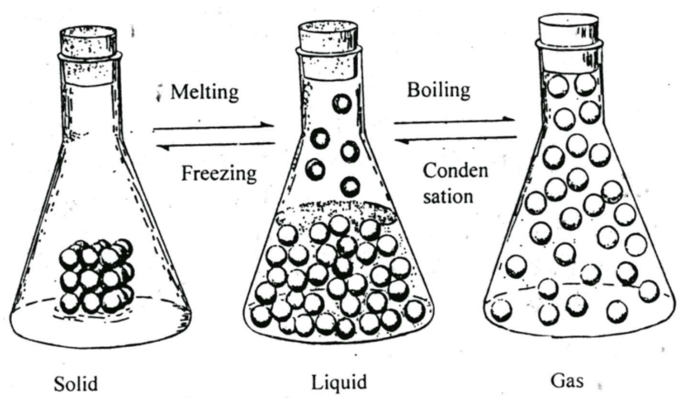


Fig 2.5 Changes of state of water

Source: adopted from by the researcher from Addis Ababa City Government Education Bureau, 2006, p. 20.

Figure 2 -- Scanned figure showing the arrangement of water particles in the three states of matter during change of state

In Figure 2, particles in ice were drawn wrongly in a three dimensional structure. Not only were the arrangement of particles incorrect but also the proximity, i.e., it implies that ice particles are closer to each other than liquid – water particles. Here, we note that in reality the particles in ice are far apart to each other relative to particles in liquid-water (this is an exception to the general trend of the arrangement of particles in solids and liquids). However, the Textbook reinforces the very common misconception that ice particles are more close to each other than liquid water particles.

Liquid-water particles were drawn distributed throughout the container; it is not because of the fact that the diagram cannot represent liquid-water particles. Rather, it represents particles in liquid-vapor equilibrium.

The particle number was not conserved in this figure even though it was drawn in a closed system. Regarding the location of particles, location of both “ice particles” and gaseous-water particles are drawn correctly (i.e. at the bottom of the container and distributed throughout the container respectively). The particles of ice and gaseous water are remaining the same in size and shape. The “liquid - water particles” are represented by different sizes and shapes, i.e. using small circles and dots. The figure represents the particles of the solid and the gaseous water as discrete, but in representing “liquid - water particles” the kind of layer using small dots reinforces the continuous nature of matter.

Hence, in Figure 2, one can easily observe (1) a confusion between liquid water particles and particles in a liquid-vapor equilibrium; (2) as if liquid water particles could occupy the whole of the container; implying that liquid water does not have definite volume; (3) a conception that there are something in between liquid particles, small dots imbedded in small circles; (4) as if liquid particles do have different sizes (small circles and dots); (5) instead of showing the level of the liquid water using the particles themselves a kind of line (using small dots) is drawn to indicate the surface boundary; (6) switching from 3D to 2D representation may create confusion for students in understanding arrangement of particles; and even the 3D arrangement of ice particles was not correct; (7) It reinforces the very common misconception that particles in solid water (ice) are more close to each other than liquid-water particles. In general, this figure fails to represent the basic behaviors of particle discreteness, conservation, proximity, orderliness of particle arrangement, locations of particles in a container, and constancy of particle size and shape.

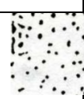
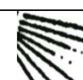
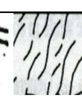
Particulate Nature in all Figures of the Textbook

For the rest of the figures in the Chemistry Textbook, particle discreteness was used as a sole criterion for analysis. The representations are categorized as discrete and continuous nature. The small circles and dots considered are representing discrete view, while lines (short, long, and curved), fuzzes, shades, and line are to indicate a layer to represent continuous nature of matter.

Gas Particles

The following table summarizes the Textbook representation of the gas particles in different parts of figures.

Table 1- Grade 7 Chemistry Student's Textbook of Addis Ababa Representation of Particles of Gases

Gases	Discrete nature		Continuous nature			
	Small dots	Small circles	Curved, lines, fuzzes			Nothing
Scanned part of figures (gases)						
Page(s)	82, 83	20, 94,120	85	119	9, 39	44,58,94,113,114,120,123,125, 126

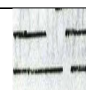
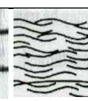
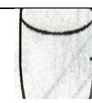
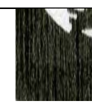
Source: Adopted from Addis Ababa City Government Education Bureau, 2006.

Gas particles are represented by small dots, small circles, curved and straight lines, fuzzes, and as nothing. Gases are represented as discrete particles in only five out of eighteen parts of figures, which is 28 percent.

Liquid particles

The following table summarizes the text book representation of the liquid particles in different parts of figures.

Table 2 - Grade 7 Chemistry Student's Textbook of Addis Ababa Representation of Particles of Liquids

Liquids	Discrete nature		Continuous nature				
	Small circles	Small circles with dots	Lines: short, long, curved			Single line	Shaded
Scanned part of figure (liquids)							
Page(s)	43	20	16,26, 36,37, 120	114, 125	9, 35, 39, 43, 85	41, 43	37, 38, 44

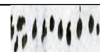
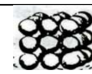
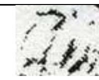
Source: Adopted from Addis Ababa City Government Education Bureau, 2006.

Liquid particles are represented by small circles, small circles with dots, lines (short, long, curved), a line to indicate a layer, and shade (see Table 2). Liquid particles are represented as discrete in only two out of twenty parts of figures, which is only 5 percent.

Solid particles

The following table summarizes the text book representation of the solid particles in different parts of figures.

Table 3 - Grade 7 Chemistry Student's Textbook of Addis Ababa Representation of Particles of Solids

Solids	Discrete nature					Continuous nature	
	Small dots		Small circles			Lines	
Scanned part of figure (Solids)							
Page(s)	37	22, 29	85, 125	9, 20	37, 38	94	25

Source: Adopted from Addis Ababa City Government Education Bureau, 2006.

Small dots, small circles, and curved lines are used to represent solid particles (see Table 3). In these figures, solid particles are represented as discrete in nine out of eleven figures, which is 82 percent. Relatively, solid particles are represented well as discrete.

It has to be noted that in this same Textbook, particles in each state of matter are represented in six or seven different patterns and that can reinforce students' misconceptions that matter is continuous.

In summary, out of the forty-nine parts of figures analyzed, only 28% of the figures of gases, only 5% figures of liquids and 82% figures of solids were found to represent discreteness of particles. From the above analysis, we can conclude that the Textbook is not sensitive and successful in presenting particles as discrete, rather it reinforces belief of continuous nature of matter.

Students’ Drawings Analysis

In order to study the implication of the Textbook on students’ conceptions, students were required to draw the particles during phase changes and their drawings were analyzed using the ‘Nature of Matter Inventory’.

Subjects

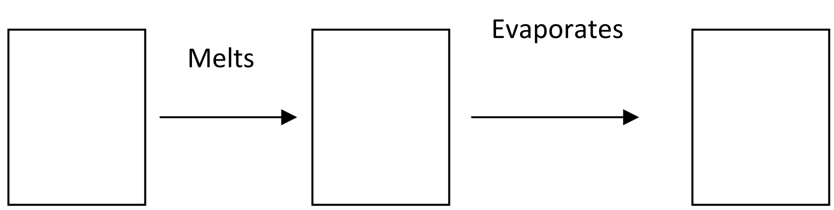
The Particulate Nature of Matter Inventory was administered to a total of 181 Grade 8 students of the three government schools in Addis Ababa. Out of the 181 students, 51.93 percent were females. The average age of the students was 14.37 years. All students thought that they had had the Grade 7 Chemistry Student’s Textbook prepared by the Education Bureau of the City government of Addis Ababa.

Instrument

To study the particulate nature of matter, students were asked to draw solid, liquid and gas particles during changes of state.

Test

Matter exists in three forms (phases): solid, liquid and gas. In box-1, draw particles in the solid phase. In box-2, draw the particles in the liquid phase. In box-3, draw the particles in the gas phase.



Box-1 Box-2 Box-3

St Solid Particles Liquid Particles Gas Particles

Students drawings were categorized as (1) all three phases represented as discrete, (2) at least one of the three phases represented as continuous, (3) all three phases represented as continuous.

Table 4 - Category and Percentage of Students' Drawings.

S. No.	Category	N=181	
		f	%
1	All three phases represented as discrete	29	16.02
2	At least one of the three phases represented as continuous	148	81.77
3	All three phases represented as continuous	4	2.20
	Total	**181**	**100.00**

Source: Own study results, 2011.

Only 16.02 percent of students drew all three phases as discrete. 81.77 students drew at least one of the three phases as continuous, and only 2.20 percent students drew all the three phases as continuous.

Students' discrete representation of all the three phases further analyzed using the checklist developed by Gabel et al. (1987) called 'Nature of Matter Inventory'. Among the 16.02 percent students who drew particles as discrete, only 3.45 percent of them correctly conserved number of particles; about seventy-two percent drew correctly proximity of particles; and about fifty-five percent of the students drew correctly orderliness of particle arrangement. Specifically, 68.97 percent of the students drew liquid particles correctly at the bottom and to the sides of the container; and 75.86 percent of them drew gas particles correctly distributing evenly throughout the container. In addition, 82.76 percent of those students drew location of solid particles correctly at the bottom of a container. Finally, from the analysis for constancy of particle size during phase changes, it was found that only 37.93 percent students drew correctly keeping the particle size constant.

Table 5 - Further Analysis of Students' Discrete Representation of the Three Phases.

	Category	N=29	
		f	%
1	All three phases represented as discrete		
	Conservation of particles	1	3.45
	Proximity of particles	21	72.41
	Orderliness of Particle arrangement	16	55.17
	Location of particles in container		
	• Bottom of the container for Solids	24	82.76
	• Bottom and to the sides of the container for Liquids	20	68.97
	• Evenly distributed for Gases	22	75.86
	Constancy of particle size and shape	11	37.93

Source: Computed by the researcher, 2011.

Conclusions and Recommendations

From the above analysis, one can deduce that the Grade 7 Chemistry Student's Textbook of Addis Ababa is a source of the students' misconceptions regarding the particulate nature of matter. Therefore, the result of this study has serious implications for chemistry text book development. The Education Bureau of the City Government of Addis Ababa should give careful attention to the figures when they describe chemistry at the submicroscopic level and text book developers should also be clearer about what they expect the figures to represent.

Researches on Remedy of Misconceptions

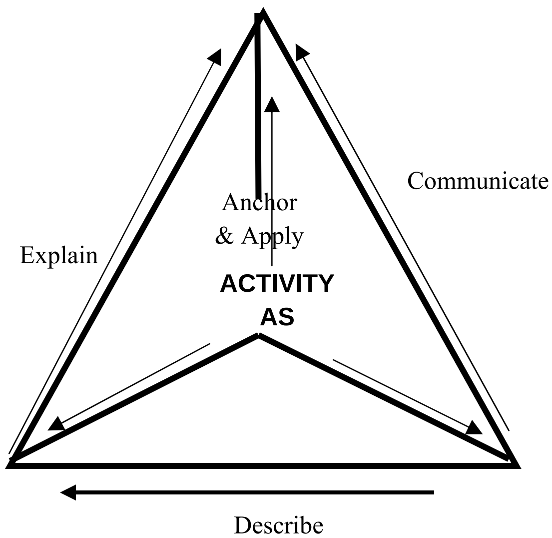
Study 1: Particulate Nature of Matter (2006-2009)

The objectives of this research were: to diagnose the major students' misconceptions about Particulate Nature of Matter (PNM), and to evaluate the students' conceptual reconstruction of the basic concepts of the PNM comparing the traditional with the suggested T-ZPD framework. In order to attain the research objectives two research questions were formulated: "What are the types of mental models regarding the nature of matter?", and "How do experimental and control groups compare in conceptual reconstruction of the PNM?"

The participants for this study were Grade 7 junior high school students from three government schools in Addis Ababa, Ethiopia. Three equivalent classes were chosen as the experimental and control groups, based on the results from the pretests. The sample consisted of 181 students (average age equals 13.37 years) in control group and 185 students (whose average age equals 13.54 years) in experimental group; which make a total of 366 students. The study population included a total of 177 males and 189 females.

Let us consider the suggested framework for remedy: Tetrahedral in Tetrahedral-in-ZPD MODEL (Sileshi, 2009; Barke 2006).

Example of conceptual reconstruction - Changes of states: instrument



PNM: Particle-

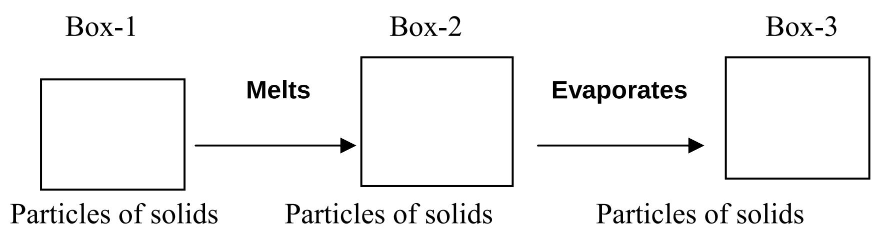
- Discreteness
- Arrangement
- Motion
- Distance
- Attraction

2.1. Considering changes in state, which of the following statements is true?

a. Solids and liquids have definite volume while gases have indefinite volume.

b. Solids, liquids and gases are made up of particles.

c. Both are correct.



(I) Students' responses for the first tier question after instruction (question 2.1)

From the post-test data analysis it was found that 83.2 percent of the control group and 90.6 percent of the experimental group students responded in line with the conception held by the scientific community, that is alternative (c).

Table 4.15 - Students' responses on changes of states after instruction

[Control: N = 179, **Experiment:** N = 181]

Teacher made multiple choice: Changes of states	**Group**	**f**	**%**
Incorrect answer	Control	29	16.2
	Experimental	**15**	**8.3**
Correct answer	Control	149	83.2
	Experimental	**164**	**90.6**
No answer	Control	1	0.6
	Experimental	**2**	**1.1**

Source: Own experimental results, 2011.

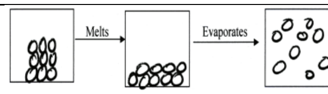
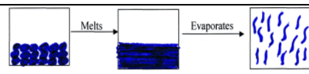
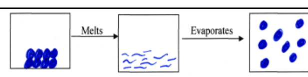
In order to better investigate students' misconceptions which are associated with changes of states, mental model drawings of those students who answered to this first tier correctly will be analyzed further in the next section.

(II) Students' drawings for the second tier question after instruction (question 2.2)

In the second-tiered question (question 2.2) students were requested to draw their mental model representations for the changes of state of matter. The findings of the experimental research are presented as under.

Table 4.16 -Students' Mental Model Drawings for the Changes of State.

[Control: N = 149, **Experiment**: N = 164]

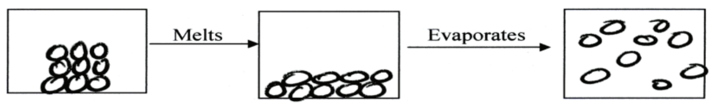
Type of drawing	Students drawings	Group	f	%
Right concept				
Type 1		Control	33	22.1*
		Experimental	**118**	**72.0***
Misconceptions				
Type 2		Control	34	22.8
		Experimental	**13**	**7.9**
Type 3		Control	15	10.1
		Experimental	**12**	**7.3**
Type 4		Control	39	26.2
		Experimental	**9**	**5.5**
Type 5		Control	25	16.8
		Experimental	**8**	**4.9**
No Category		Control	3	2.0
		Experimental	**4**	**2.4**

Source: Own experimental results, 2011.

(III) Comparison of the students correct mental model drawings after instruction

Descriptive

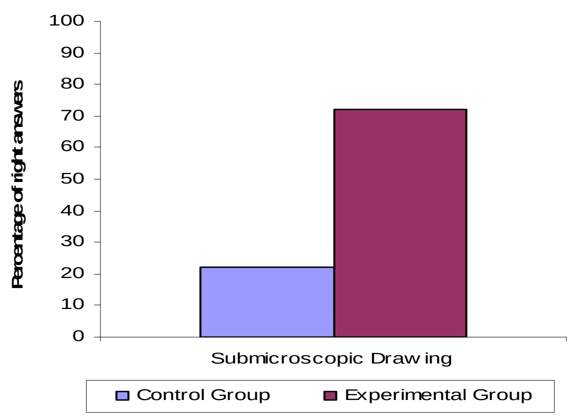
Out of the 83.2 percent of the control group who responded correctly to the teacher made multiple choice questions, only 22.1 percent of the students were found to draw the correct mental model drawing. Similarly, out of 90.6 % of the experimental group, 72.0 percent of those subjects drew their mental model models correctly.



Source: Designed by the author, 2011.

The following figure illustrates the comparison made between those subjects in the experimental group and those in the control group regarding the total percent of those students who drew correctly their mental models correctly after instructions had been given.

Figure 4.40 -- Students' correct mental model drawings.



Source: Own experiment results, 2011.

Analysis of Data

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 could be compared using an independent *t*-test.

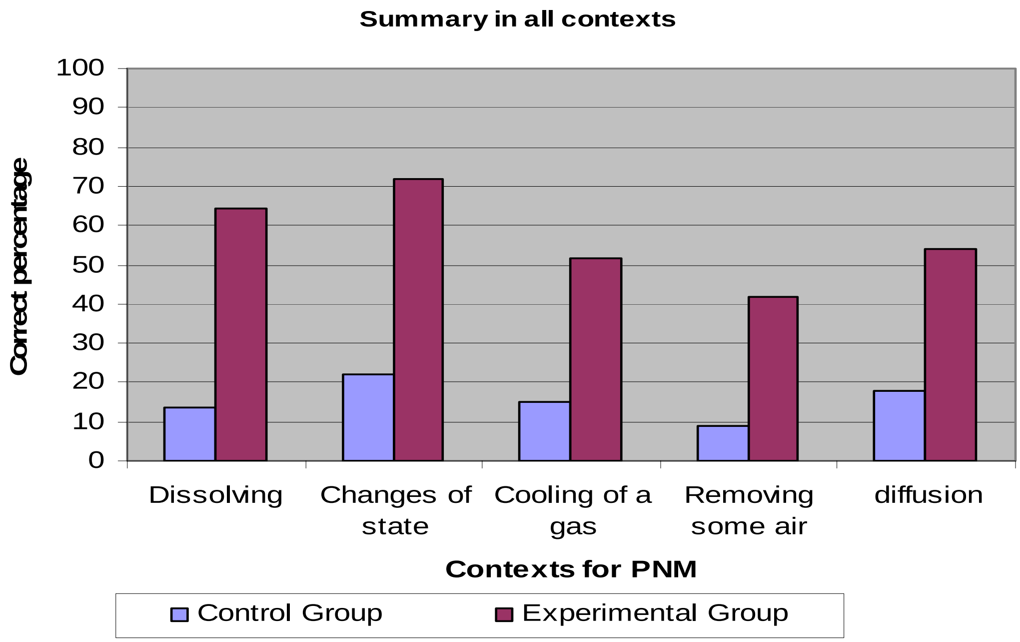
The data showed that there was a statistically highly significant difference in post test scores of the experimental group (M = .7195, SD = .45061) compared to the control group (M = .2215, SD = .41664) t= -10.121, $p < .05$ (Table 4.17 and figure 4.38). Note that the mean difference between the two groups is .4980, it is very high.

Table 4.17-- Group Statistics and Independent Samples Test Concerning the Three States of Matter

		Post-test				
Question 2.2	Group	N	M	S.D.	t (df= 311)	p
Students' correct mental model drawing on changes of state.	Control	149	.2215	.41664	-10.121	.000*
	Experimental	164	.7195	.45061		

Note: *p < .05

Source: Own data analysis outputs, 2011.



Source: Own data analysis outputs, 2011.

In the above-stated experimental research, a statistically significant difference ($p<0.05$) was obtained while comparing their post-tests in favor of the T-ZPD group students.

Study 2: Chemical Reaction: Diagnosis and Towards Remedy of Misconceptions (2010).

Summary

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 was conducted in high school chemistry classes in Addis Ababa, Ethiopia. The subjects of the main study included a total of 164 students. The Chemical Reaction - Concept Inventory was administered to both groups as pre- and post-tests, followed by conducting interviews with some of the selected students. The results of the independent t-test on students' post-test scores on the concept inventory of chemical reaction showed that the T-ZPD group students' conceptual reconstruction towards the scientific concept was found to be statistically significantly better than those students in the traditional group.

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.

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

To attain the above-sated major purpose of the research, 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/Subjects

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 of the pre-tests. The sample consisted of 84 students (whose average age equals to 16.37 years) in control group and 80 students (average age equals to 16.54 years) in experimental group; which make up 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. We note that those students whose response is correct to both tiers considered to have the correct basic conceptions of coefficients and subscripts. Students who responded to the first tier correctly but could not answer or draw in the second tier were considered as having misconceptions. And if students' responses to the two questions were incorrect or for the first question correct but for the second tier incorrect they were considered as students with "no understanding".

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

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

Source: own research results, 2010.

Results

The pre-test 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 (see Table 2 below). 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

Question type	Group	Pre-test					Post-test				
		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		

Note: *$p < .001$

Source: Outputs from own study data analysis, 2010.

As there were no significant differences between the pre-test scores of the experimental and that of the control groups, the post-tests scores of the groups were compared using an independent *t*-test.

The outputs of data analysis showed that there was a highly statistically 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, $p < 7$.

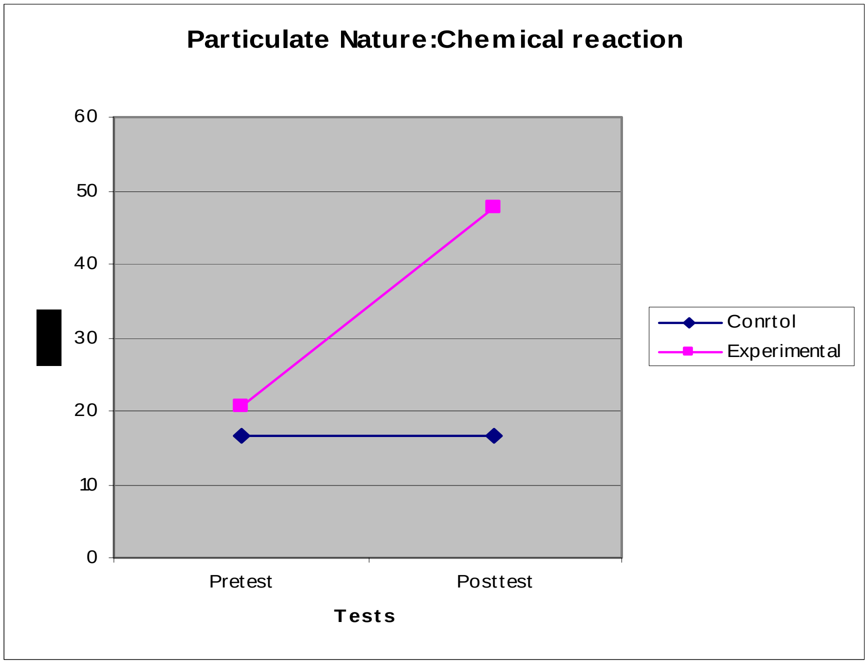


Figure 7-- Mean percentage for pre and post tests

Source: Outputs from own experimental study, 2010.

Recommendations

Curriculum

The teaching material should be written by taking into account the four major dimensions of the Tetrahedral-in-ZPD Chemistry education Approach, namely, Context, Submicroscopic, Submicroscopic, and Symbolic.

Instructions

Instructions should be given in the framework of the Zone of Proximal Development (ZPD). In addition, it should use a variety of symbolic representations. In this study, among 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 the preparation of instructions emphasis should be given to molecular models, role play and concept cartoons.

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.

Example 1:

Tier 1:

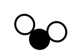
Balance the following reaction: H_2 + O_2 $\longrightarrow$ H_2O

____

Tier 2:

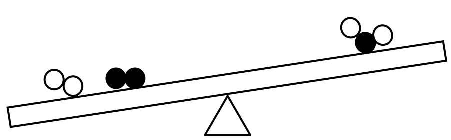
Looking carefully at the drawings below, write their appropriate chemical reactions on the space provided.

Let:

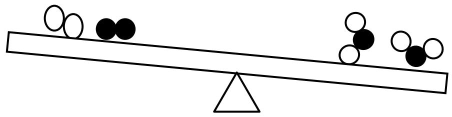
 = Hydrogen molecule,  = Oxygen molecule,  = Water Molecule

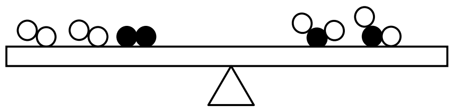
Drawing: Chemical reaction:

1.



= $H_2 + O_2 \longrightarrow H_2O$

2.  = ____________________

3.  = ____________________

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