

**AFRICAN JOURNAL OF CHEMICAL EDUCATION**  
**AJCE**



**Vol. 1, Number 1, January 2011**



*A Publication of*

[www.faschem.org](http://www.faschem.org)

# **AFRICAN JOURNAL OF CHEMICAL EDUCATION**

## **AJCE**

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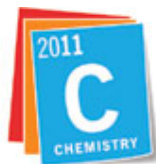
## EDITORIAL

### **IYC-2011: AN OPPORTUNITY AS WELL AS A CHALLENGE TO AFRICAN CHEMICAL EDUCATORS**

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Welcome to the maiden issue of the African Journal of Chemical Education (AJCE) published by the Federation of African Societies of Chemistry (FASC). We are happy to launch the Journal right at the time when world chemists are beginning to celebrate the International Year of Chemistry.

The idea of International Year of Chemistry (IYC-2011) was initiated by IUPAC at its 44<sup>th</sup> Council meeting



International Year of  
**CHEMISTRY**  
2011

in Torino, Italy in 2007. In that meeting the IUPAC Council also decided that the Federation of African Societies of Chemistry (FASC), in collaboration with the Chemical Society of Ethiopia (CSE), should play a critical role in obtaining UNESCO support for the declaration of 2011 as an International Year of Chemistry. IUPAC's letter dated 7 September 2007 specifically stated that they "wish to formally invite the Federation of African Societies of Chemistry to work with the Ethiopian Chemical Society to jointly place a resolution to this effect on the agenda of the Executive Board of UNESCO".

The invitation was accepted very positively though we knew that achieving the request involves a lot of diplomatic efforts. Thanks to the Government of Ethiopia's

willingness to accept and process the request as per the rules and regulations of the UNESCO Executive Board as well as that of the UN General Assembly, the 179<sup>th</sup> session of the Executive Board of UNESCO approved the proposal and then the UN General Assembly declared 2011 as the International Year of Chemistry at its 63<sup>rd</sup> meeting in December 2008. I would like to take this opportunity to thank the delegations of the Government of Ethiopia in Paris and New York. We have now reached at the stage of kicking off the IYC 2011 throughout the world.

IYC-2011 was declared with the objectives of:

- Increasing the public appreciation and understanding of chemistry in meeting world needs;
- Encouraging the interest of young people in chemistry;
- Generating enthusiasm for the creative future of chemistry;
- Celebrating the role of women in chemistry or major historical events in chemistry, including the centenaries of Marie Curie's Nobel Prize and the founding of the International Association of Chemical Societies. (1;2)

I see such educational objectives as great opportunities to African chemical educators for many reasons. We chemical educators in the continent have been complaining that Chemistry has not been the first, not even second or third, option for many youngsters while joining universities and colleges. We have also been arguing that many of our students do not have a proper understanding of Chemistry thereby hindering their ability to be creative citizens. Furthermore, the public at large has a distorted image of Chemistry in which the subject is perceived negatively by being associated with explosives, toxics, etc. The proportion of female Chemistry professionals is also very much low. In addition, the visibility of African chemical societies in the international arena is very much limited. For instance, only 5 African countries are registered as IUPAC's National Adhering Organizations (NAO). According to IUPAC (3), NAOs are the formal Members of the

Union, which represent the chemists in those countries. Similarly, only 9 countries are members of the Federation of African Societies of Chemistry.

The goals of IYC-2011 therefore seem to address such concerns of African chemists and teachers. We need to use this opportunity since IYC-2011 is expected to attract the attentions of our respective governments, private sectors, academia and the public at large. What else can be an opportunity other than this one? We need not, however, merely focus on celebrating the event as a public holiday but rather on maximizing the utilization of the Year towards achieving the intended goals.

On the other hand, the Year poses a challenge to African chemical educators. Appreciation and proper understanding of Chemistry, young people's interest and creativity in Chemistry, and enhanced female participation in the chemical sciences can be achieved and development in Africa would be sustained if and only if African chemists and educators are able to provide contextualized, relevant and meaningful educational experiences to the young generation—at primary, secondary, undergraduate and postgraduate levels of chemistry education. I personally feel that little has been done in this regards and I even doubt that this can be appreciated by many of us in Africa. This is what I mean by the challenge in achieving the goals of the IYC-2011 in Africa. It is, in fact, clear that one group of professionals cannot alleviate the entire problems we are facing. It is necessary for professionals in basic science (chemistry), chemical education, technology and even education policy to work together in addressing the following issues (4, 5, 6):

- Which resources are available in the immediate surroundings of our schools/colleges?
- To what extent has basic research in science and technology investigated the local (African) resources? How can their uses be maximized in chemistry education?
- Are there efforts on the part of African chemical educators to develop and validate teaching strategies (models):
  - whose implementations are primarily based on the use of local materials?

- whose theoretical bases are the investigation of indigenous knowledge?
- which can successfully be applied in large classes with limited resources?
- Can we, simply because of our large classes and limited resources, continue with our traditional methods of imparting knowledge (lower order cognitive skills) to students and still be active participants of the 21st century?
- Are there science education policies that guide and encourage the development and implementation of such tasks?
- Are the professionals ready both intellectually and attitudinally to carry out reforms in African chemistry education, or should such programs be still left aside as minor priority areas?
- In what respect and how can we learn from the experiences of the developed nations?

Some of these challenges could be detected and addressed by the papers discussed in this issue. The first research paper is from Ethiopia, the second and fourth from Egypt, and the third one from Nigeria. All these countries were the founding members of FASC, though the contributors are individuals. In addition, this first issue has brought to you the professional opinions of Prof. Peter Mahaffy from Canada and the Chair of the Committee on Chemistry Education of IUPAC.

Enjoy reading them and have a successful IYC-2011!

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## INTERVIEW WITH PROFESSOR PETER MAHAFFY



***Peter Mahaffy** is deeply committed to helping students, educators, and the general public see the intricate web that connects chemistry to so many other aspects of life and to the health of our planet. He was born in East Africa, obtained his PhD in Physical Organic Chemistry from Indiana University (USA), and is now Professor of Chemistry at the King's University College in Edmonton, Alberta, Canada and Co-director of the King's Centre for Visualization in Science. Mahaffy collaborates regularly on research with undergraduate students in the areas of chemistry education, visualization in science, organic chemistry, and environmental chemistry. He chairs IUPAC's Committee on Chemistry Education (CCE) and led the team that obtained UN designation of 2011 as an International Year of Chemistry. His awards for contributions to chemistry education include a Fellowship of the Chemical Institute of Canada (CIC); the CIC National Award for Chemistry Education; and Canada's National 3M Teaching Fellowship. Over the past five years, he has worked with two Australian co-authors to create an integrated text and electronic learning resource for teaching 1<sup>st</sup> year university chemistry, called "Chemistry: Human Activity, Chemical Reactivity," published this year by Nelson Canada, and distributed in Africa by Cengage Learning.*

The Editor-in-Chief (EIC) of this journal (AJCE) requested Prof. Mahaffy to provide his responses to written interview questions and the following paragraphs present the questions and his responses. EIC greatly thanks Prof Mahaffy for his willingness to offer the responses.

**EIC:** Please tell us about your conceptions of Chemical Education: its meaning, scope, etc.

**Mahaffy:** I prefer the term "chemistry education" to "chemical education." Chemical education is education about chemicals, their structures, properties, and reactions.



Chemistry education is a bigger term that includes what we have described as “chemical education,” but also emphasizes that chemistry is always a human activity. People are involved in the practice of carrying out and investigating chemical reactions. I like to think of chemistry education as a seamless exercise in bringing together our understanding of chemical reactivity with human activity. Chemistry education should highlight the ways in which all people benefit from the chemical reactions we have come to depend on in modern life. And we need to be reminded in this profession that the teachers and learners who study chemistry are also people. To be effective chemistry educators, we need to understand the learning needs and different learning styles of our students to equip them to contribute to using the tools of chemistry to improve the human condition and that of our environment, and to help each one of them understand the crucial role that chemistry plays in our lives.

**EIC:** *What is the relationship between Chemistry and Chemical Education? Can we say Chemical Education is a (special) field of Chemistry? Can we study it? How?*

**Mahaffy:** Chemistry education has become an interdisciplinary area of professional focus, with a well developed understanding of best practices and a research domain that investigates how best to communicate chemistry to students. It is important that chemistry education be formally studied by those who wish to be chemistry teachers at any level, and that teaching is based on what we know about (a) how students best learn and (b) how they best learn chemistry. I like to use the metaphor of “tetrahedral chemistry education’ to describe four levels at which teachers need to help learners engage chemistry: These include the observable, symbolic, and molecular levels, but with constant reference to the human beings who carry out and make use of chemistry and those who learn it within and outside of classrooms and laboratories.

**EIC:** *Based on your experiences in your country as well as in others, would you tell us some best practices in the education of chemistry teachers? What are the pre-requisites to be admitted to the programs? Who trains them? For how long? What*

*are the building blocks/content areas for the would-be chemistry teachers programs?*

*Etc.*

**Mahaffy:** First of all, there is never ‘one size that will fit all.’ Maybe the most important things that can be done at a national level are to raise the status of teachers, including science teachers, so that some of the most gifted students will seek this out as a profession. This means that chemistry education needs to be taken seriously by the public, by the education profession, and by ministries of science and technology working hand-in-hand with ministries of education to design programs to train teachers in light of national priorities and an understanding of how chemistry can play a role in meeting those priorities. This includes the interfaces of chemistry with the environment, health and medicine, materials, and energy. I think it is also important that education is provided both in chemistry (for those who go on to careers in science and technology) and about chemistry (for all citizens who need to make informed decisions about the many societal issues that involve chemistry). The former is usually part of chemistry education programs. The latter is highly undervalued in many places in the world.

To equip a chemistry educator requires giving him or her expertise in chemistry as well as in education. Increasingly I am convinced, however that it is not sufficient for an instructor to possess subject knowledge and knowledge of pedagogy. Master teaching of science also requires attending to the overlap between these two areas - the repertoire of conceptual and pedagogical knowledge grounded in the beliefs and practices of the teacher. This *pedagogical content knowledge* seems important to properly equip science educators to teach specific aspects of the subject matter to a particular group of students at the appropriate level for their education in science. And this pedagogical content knowledge will be quite different for someone wanting to teach at the elementary, secondary, or tertiary level.

**EIC:** *Is there any exemplary country or program in which the CCE of IUPAC has attempted to modernize the education of chemistry teachers in the world? What lessons can we learn from that? Any intention to improve the support in the future, particularly for African countries?*

**Mahaffy:** In African countries, as in many others, status of teachers is perhaps one of the biggest barriers to improving the chemistry education system, and this must be one of the starting points. A second major focus for chemistry education reform would be to move from teacher-centred approaches where learners are quite passive, to much more active learning which outlines clearly what the learning goals are for students and then helps them meet their own learning goals. And one of the very significant challenges is always the provision of hands-on experiences. Chemistry is a creative science, and learners need to be able to create things in simple laboratory experiments to develop an authentic understanding of the domain of chemistry and to prepare them for working in the many chemistry related industries and professions.

The IUPAC committee on chemistry education, which I chair, now has experience of working with several countries to help them assess their own needs in the area of chemistry education, and explore ways in which they can improve. One such program is the IUPAC Flying Chemist Program, which Ethiopia is presently carrying out, and which will culminate in a two-day meeting in February 2011, where the results of a survey of chemistry education will be assessed and specific actions brought forward to improve the teaching and learning of chemistry. This program has previously been carried out successfully in India, Sri Lanka, the Philippines and in Croatia.

**EIC:** *What do you want the chemistry community in Africa to do in the area of chemical education in IYC-2011 and beyond?*

**Mahaffy:** The global chemistry profession, including the International Union of Pure & Applied Chemistry has worked together with UNESCO to organize 2011 as an

International Year of Chemistry. We are deeply indebted to African countries for the vital role they have played, both in obtaining support for this initiative at UNESCO and the UN, and also in helping to articulate what the world should celebrate and be challenged to think about in 2011. Two major themes have emerged: To understand and promote better the role of chemistry in the sustainable development of our planet, and on the 100<sup>th</sup> anniversary of the awarding of the Nobel Prize in Chemistry to Marie Slodowska Curie, to celebrate the role of women in chemistry. We hope that both of these areas will be a focus of celebrations of chemistry in Africa in 2011 and beyond. We hope that young people will discover the stories of chemistry achievement in each of their own countries and communities, and that those who are currently in school will use the tools of chemistry to help make this world a better place.

**EIC:** *Any thing that you want to add.*

**Mahaffy:** I am honored to be able to contribute to this first issue, and would like to congratulate you and your colleagues for taking the important steps of implementing a mechanism to communicate with each other about developments in chemistry education.

**EIC:** Thank you again for taking your time in giving written responses to the above questions to be published in the first issue of the African Journal of Chemical Education (AJCE).

## **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?

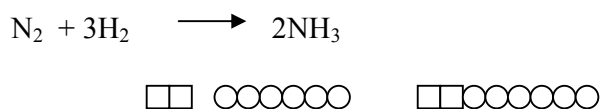
In balancing equations, it is important to understand the difference between a coefficient of a formula and a subscript in a formula. The coefficients in a balanced chemical equation can be interpreted both as the relative number of molecules, moles or formula units involved in the reaction. And subscripts 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

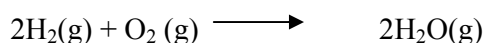
students' school learning is like a veneer—on the surface they are able to perform the required operations, but there is little depth of understanding (4).

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  $\bigcirc$  is Hydrogen Atom) students represented  $3H_2$  as  $\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$  rather than  $\bigcirc\bigcirc \bigcirc\bigcirc \bigcirc\bigcirc$ . 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:



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



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).

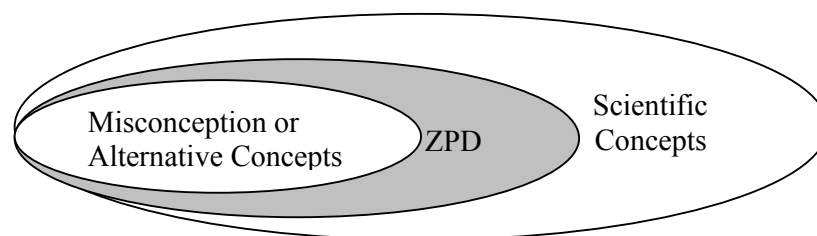


Figure1: Applying ZPD (Zone of Proximal Development) to science education

## 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.”

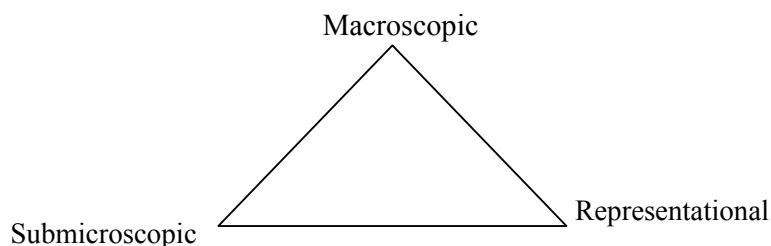


Figure 2: Johnstone's Trigonal Approach

## **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.

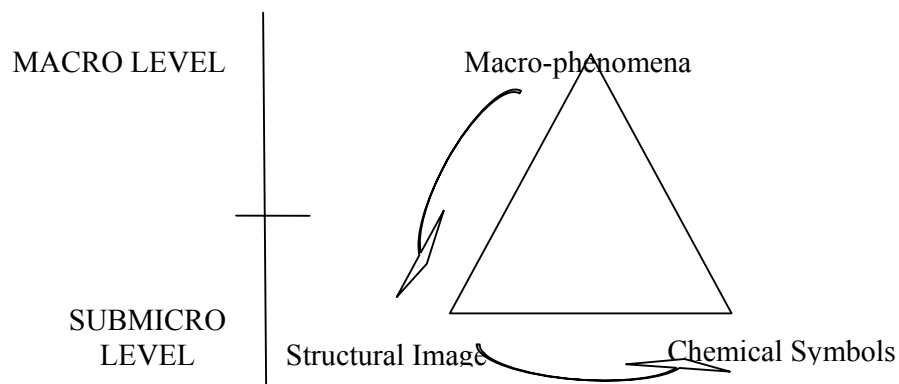


Figure 3: Barke and Engida's Structural Oriented Approach

### 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 approach 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).

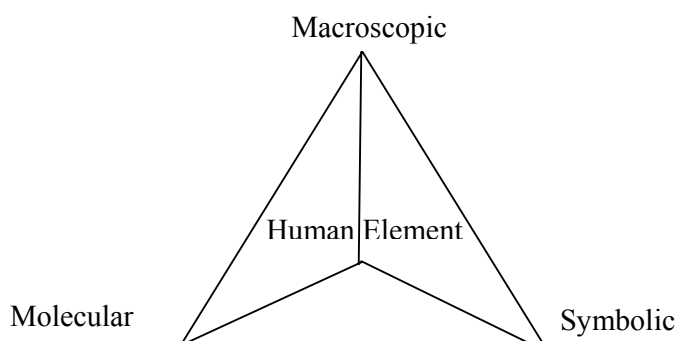


Figure 4: Mahaffy's Tetrahedral Approach

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 societal-

technological-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.

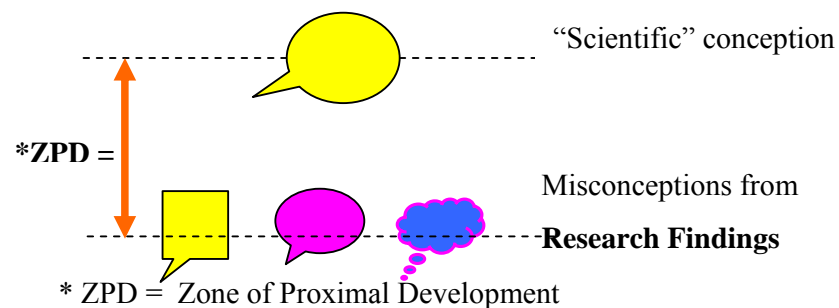
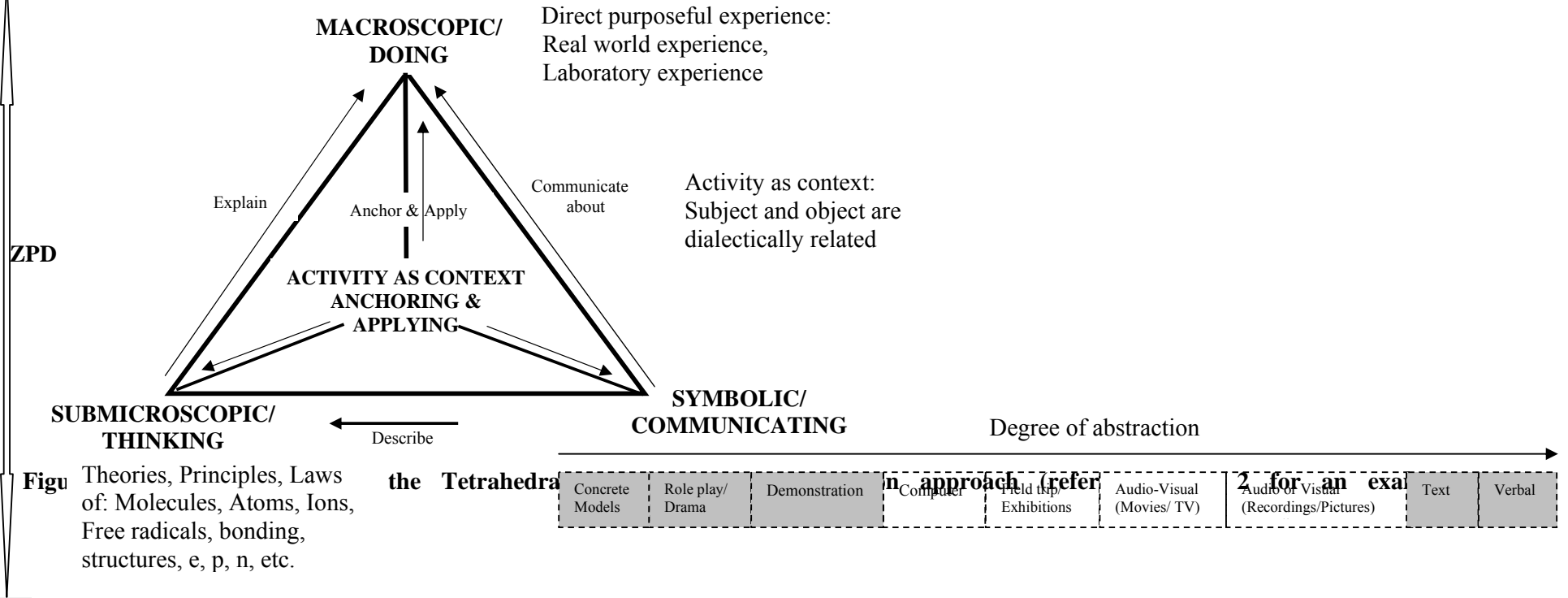


Figure 5: Concept cartoon as a strategy to incorporate research findings

### Tetrahedral in ZPD Chemistry Education Approach (24)

SCIENTIFIC CONCEPTS or Currently accepted concepts by the scientific community



**Figure 2. The Tetrahedra**  
Theories, Principles, Laws of: Molecules, Atoms, Ions, Free radicals, bonding, structures, e, p, n, etc.

MISCONCEPTIONS OR ALTERNATIVE CONCEPTIONS

### 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	
Incorrect	Correct	No- understanding



**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

Question type	Group	Pretest					Posttest				
		N	M	S.D.	t (df)	p	N	M	S.D.	t (df)	p
(i) Balancing	Control	81	.7407	.44096	.726 (156)	.469	84	.78579	.4127	-.843 (162)	.400
	Experimental	77	.6883	.46622			80	.83754	.3712		
If the equation was correctly balanced:											
(ii) Representing the balanced equation using diagrams	Control	60	.1667	.37582	-.553 (111)	.581	66	.16673	.3755	4.034 (131)	.000
	Experimental	53	.2075	.40943			67	.47767	.5032		

\*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).

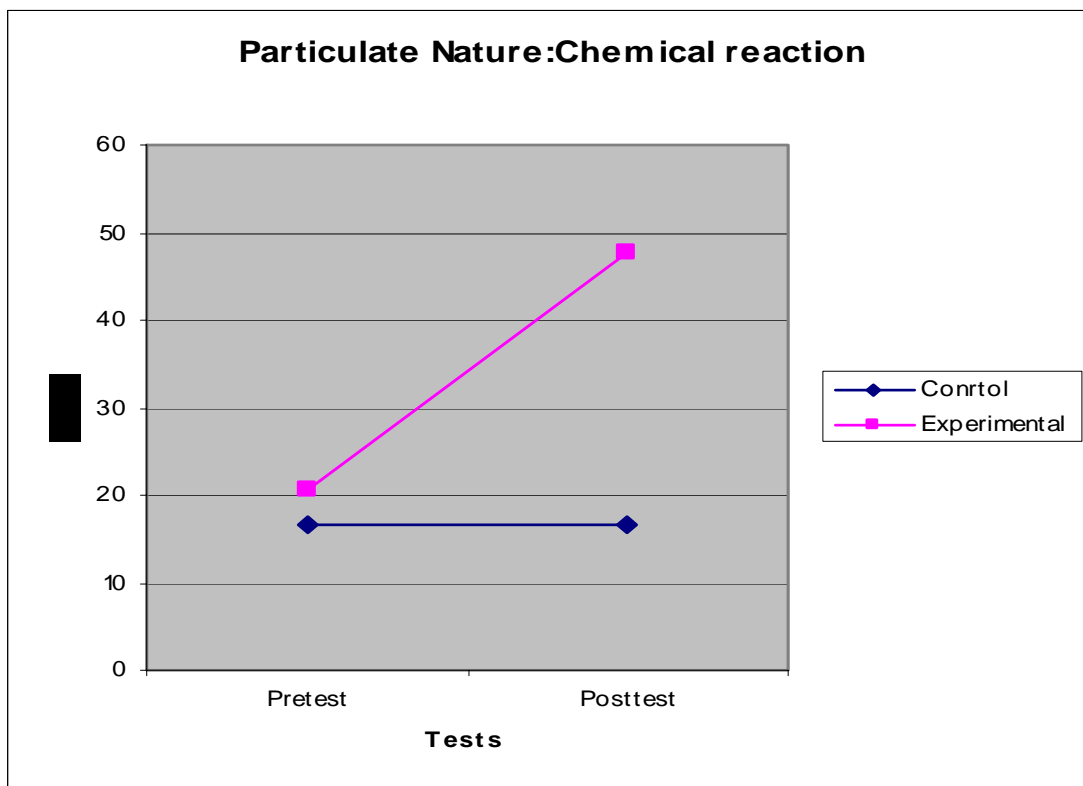


Figure 7: Mean percentage for pre and post tests

## 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:  $\text{H}_2 + \text{O}_2 \longrightarrow \text{H}_2\text{O}$

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*Tier 2:*

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

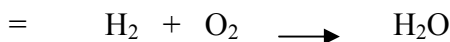
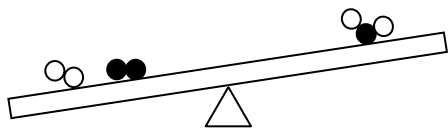
Let:

 = Hydrogen molecule,  = Oxygen molecule,  = Water Molecule

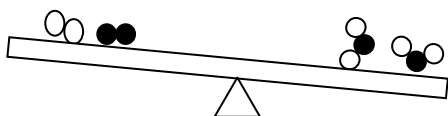
Drawing:

Chemical reaction:

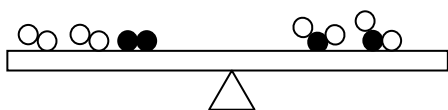
1.



2.



3.



Example 2:

Tier 1:

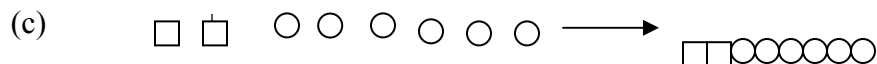
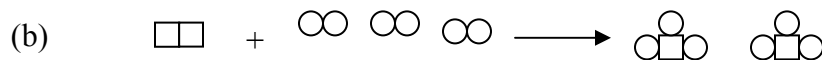
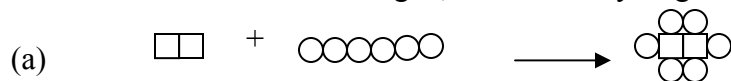
Balance the following reaction:  $\text{N}_2 + \text{H}_2 \longrightarrow \text{NH}_3$

\_\_\_\_\_

Tier 2:

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

Let:  $\square$  = Nitrogen; and  $\circ$  = Hydrogen



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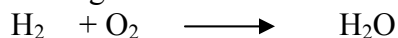
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## Appendix 1

### Example: pretest and posttest

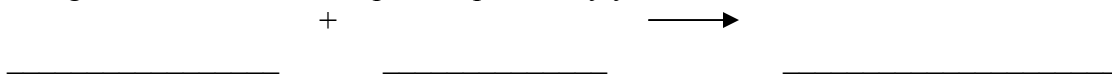
Pretest:

Tier (i) Balance the following chemical reaction:



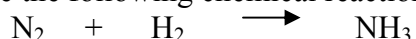
Tier (ii) Let:  $\square$  = Hydrogen atom, and  $\bigcirc$  = Oxygen atom

Using the above notations represent pictorially your balanced chemical reaction.



Posttest:

Tier (i) Balance the following chemical reaction:



Tier (ii) Let:  $\square$  = Nitrogen atom ; and  $\bullet$  = 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.

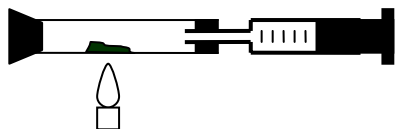


### Macroscopic

- 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.

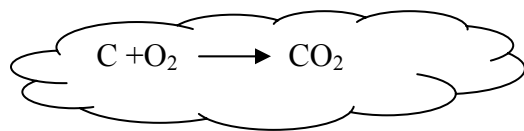
#### Activity 2 Role Play

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.

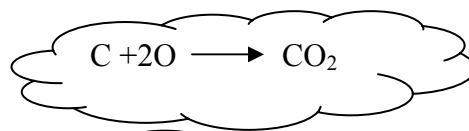
Write the balanced chemical reaction between carbon and oxygen based on the role-play.

#### 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 think is right?

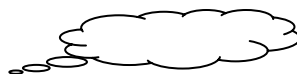


Aster



Abebe

What do you think?



## **THE SYSTEMIC APPROACH TO TEACHING AND LEARNING [SATL]: A 10-YEAR REVIEW**

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### **ABSTRACT**

The Systemic Approach to Teaching and Learning (SATL) is based on constructivist principles and involves the creation of closed cluster concept maps called systemic diagrams. The SATL technique encourages deep learning, as opposed to rote learning. Examples in the use of SATL methods in teaching chemistry are presented. Experimental evidence collected in Egyptian schools is presented to illustrate the efficacy of SATL methods on student achievement. It is suggested that SATL methods mimic our current understanding of how the human brain functions, as the basic reason that SAL methods are successful. [*AJCE, 1(1), January 2011*]



## INTRODUCTION

About a decade ago the authors formulated their basic ideas on the Systemic Approach to Teaching and Learning (SATL). In the intervening time, SATL methods have been refined and their usefulness in disciplines other than chemistry has been established. Most of the developmental efforts on SATL methods have been expressed in chemistry-oriented subjects at virtually every educational level. We present here the current status of SATL methods.

Our primary professional interests have always been helping teachers teach and students learn more effectively, and we believe the SATL technique described here has additional benefits to societies that face issues of globalization. Economics, media, politics, and banking are among the human activities that have achieved a global, as opposed to a regional or a local, perspective. Science education—that process by which progress in science is transmitted to the appropriate cohort of world citizens—must be sufficiently flexible to adapt to an uncertain or, at best, ill-defined global future. That future, however, ultimately must include an appreciation of the vital role that scientists and chemists, in particular, play in human development. Thus, the future of science education must reflect a flexibility to adapt to rapidly changing world needs. It is our thesis that a systemic view of science with regard to principles and their internal (to science) interactions as well as the interactions with human needs will best serve the future world society. Through the use of a systemic approach, we believe it is possible to teach people in most areas of human activity—economic, political, and scientific—to practice a more global view of the core science relationships and of the importance of science to such activities.

As a start, we suggest the development of an educational process based on the application of “systemics,” which we know (*vide infra*) can affect both teaching and learning. The use of systemics can help students begin to understand interrelationships of concepts in a greater context, a point of view, once achieved, that ultimately should prove beneficial to future citizens

of a world that is becoming increasingly globalized. Moreover, if students learn the basis of the systemic process in the context of learning chemistry, we believe they will doubly benefit; learning chemistry and learning to see *all* subjects in a greater context. In this regard, anecdotal evidence exists (*vide infra*) that students who learn chemistry using SATL techniques are able to transfer that learning process to other disciplines.

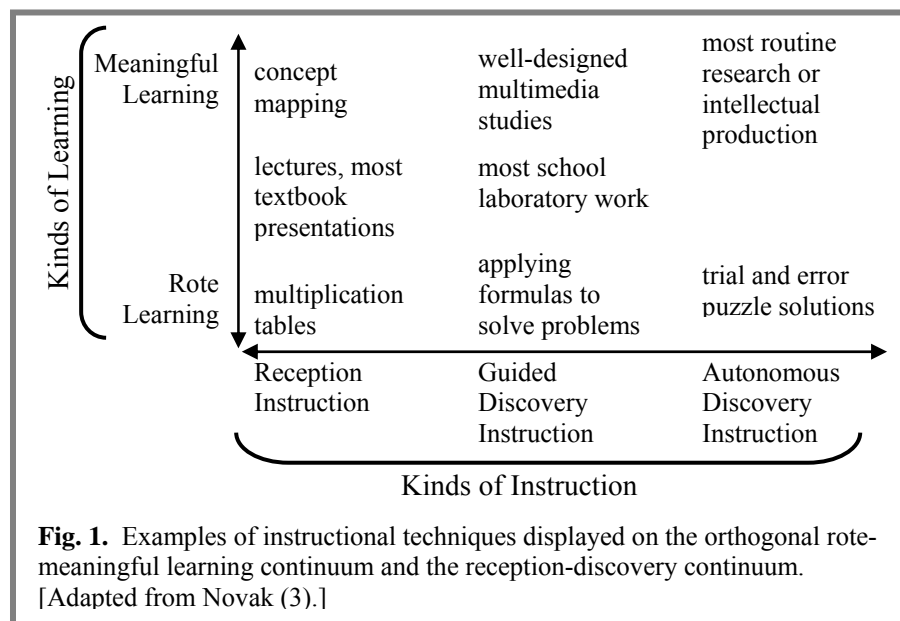
## THE ROOTS OF SYSTEMICS

The basic SATL concepts are derived from Constructivist ideas. A number of excellent reviews of the current status of Constructivist thought are available, among which is the book edited by Fosnot (1) that can guide the interested reader through the milieu of teaching and learning strategies that incorporate constructivist ideas. Here we are interested in the historic roots of constructivism from which these modern ideas have evolved.

**Constructivism.** The concept of constructivism is like a great river, both have multiple, important roots; the choice of the single most important root does not accomplish much for understanding. Historically, modern constructivist ideas can be traced back to the 18<sup>th</sup> century philosopher, Giambattista Vico who maintained that humans can understand only that which they themselves have constructed (2). The “modern” roots of constructivism go back to Jean Piaget (3) who, in 1955, first used the term “constructivist.” A number of workers have contributed to these ideas, including John Dewey (4,5). More recent scholars include Von Glasersfeld (6), Vygotsky (7), and Bruner (8). Constructivist ideas have appeared also in the chemical education literature (9-11). We choose here to pick up the thread of constructivist ideas that can be attributed to Ausubel (12,13).

In the early 1960s, when behaviorist theory prevailed among educational psychologists, Ausubel published a book entitled *The Psychology of Meaningful Verbal Learning* (13) in which he elaborated on constructivist ideas. Ausubel introduced the idea of *meaningful* learning (as opposed to rote learning). Contemporary assimilation theory stems from Ausubel’s views of human learning that incorporates cognitive, affective, and psychomotor elements integrated to produce *meaningful* learning. To Ausubel, meaningful learning is a process in which new information is assimilated into a relevant aspect of an individual’s existing knowledge structure and which, correspondingly, must be the result of an overt action by the learner. Using Ausubel’s words, new knowledge is *subsumed* by the learner into his/her current knowledge structure. Teachers can encourage this choice by using a variety of tools. It is postulated that continued learning of new information relevant to information already understood produces constructive changes in neural cells that already are involved in the storage of the associated knowledge unit. An important component in Ausubel’s writing has been the distinction he emphasized between the rote—meaningful learning continuum and the reception-discovery continuum for instruction. The orthogonal relationship between these two continua is illustrated in Fig. 1.

According to Ausubel, the essence of the meaningful learning process is that symbolically expressed ideas are related to what the learner

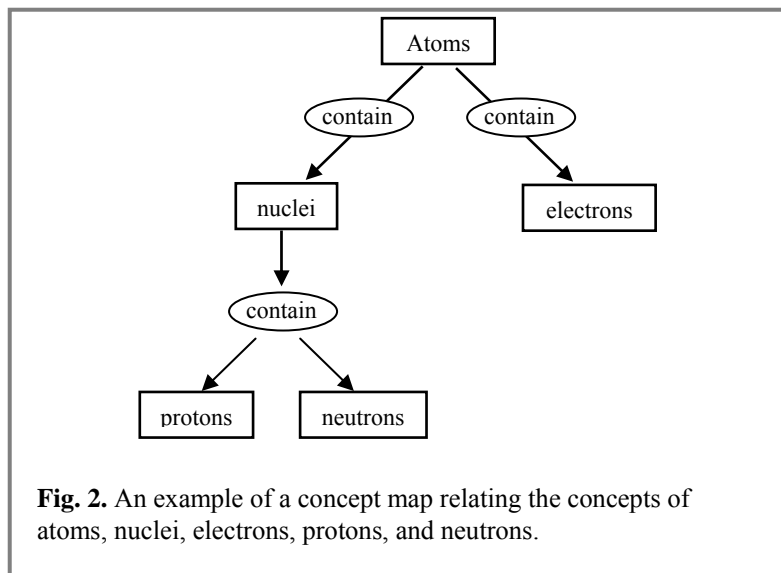


already knows. Meaningful learning presupposes that the learner has a disposition to relate the new materials to his or her cognitive structure and that the new material learned will be potentially meaningful to him or her. In other words, it takes an overt act by the learner to make learning meaningful.

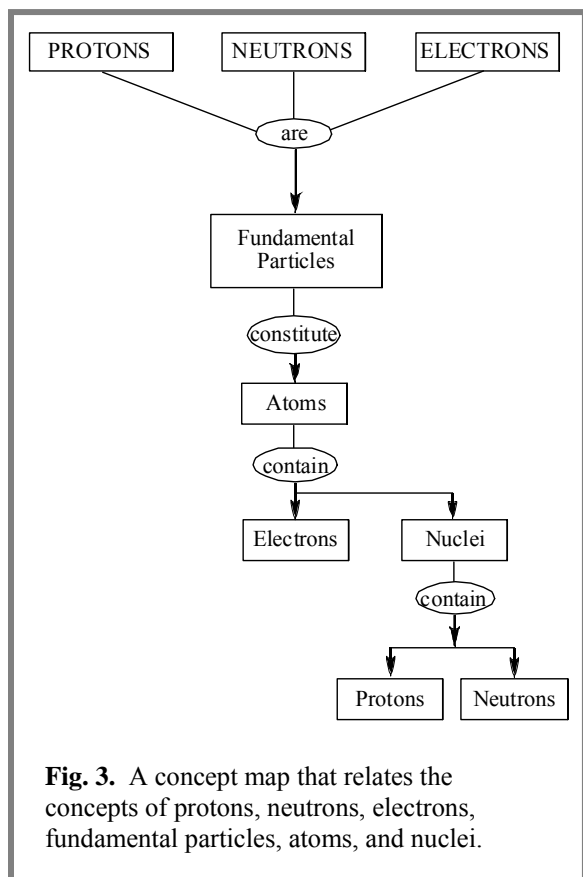
**Concept maps.** Concept Mapping is a tool developed by Novak and Gowin (14,15) designed to reveal interrelationships among concepts. A concept map is a concise, two-dimensional representation of a learner's multi-dimensional concept/prepositional framework of a particular domain of knowledge. As an example of a concept map, consider Fig. 2, which maps the concepts of atoms, nuclei, electrons, protons, and neutrons. Concepts are linked by words that establish propositions involving the linked concepts, e.g., “atoms contain nuclei”

The concepts with their linking relationships now become visible in a concept map showing the organization of concepts in the learner's cognitive structure. Concept maps can reveal misconceptions that may exist in

a student's mind; they also can be employed by teachers to illustrate the relationships that the teacher wants the student to learn. Thus, concept maps are tools that both students and teachers can use to further their own purposes—teachers to teach and assess and students to learn.



**Fig. 2.** An example of a concept map relating the concepts of atoms, nuclei, electrons, protons, and neutrons.



Care must be taken to recognize that several different, but acceptable, maps may be used to illustrate relationships among the same group of concepts. Consider the concept map shown in Fig. 3 that involves an acceptable, but different relationship amongst the concepts shown in Fig. 2. Note that the arrangement of the same concepts (except for the “fundamental particle concept”) is different, but acceptable (correct). Note that the introduction of the “fundamental particle” concept produces a concept map that is, perhaps, intuitively “less esthetic” than that in Fig. 2, but it is not “wrong”. It could be argued

that the concept map in Fig. 3 contains redundancies and, hence, is less “desirable” than that in Fig. 2. On that basis, it might not receive full marks, but this is a judgment call.

Our interest in concept maps here is their relationship to the systemic diagrams that are a key element in the SATL technique as representations for teaching and learning chemistry in a global manner.

### CLOSED CLUSTER CONCEPT MAPS

In the systemic approach, we strive to organize subjects in “closed-cluster concept maps,” (Fig. 4) which, in contrast to standard concept maps, do not continue to proliferate in ever-expanding tree-like structures (e.g., Fig. 3). Notice that, in the closed concept structure (Fig. 4), there is also an implication of multi-pathway relationships that may or may not be

important to the student (or teacher) at a given moment of understanding, but which may be “revealed” at a later time. In this sense, closed concept clusters are complete unto themselves, which is to be contrasted with “standard” concept maps. Thus, all the relationships in a closed cluster need not be explicitly taught, but they are there to be used as necessary, e.g., perhaps for assessment.

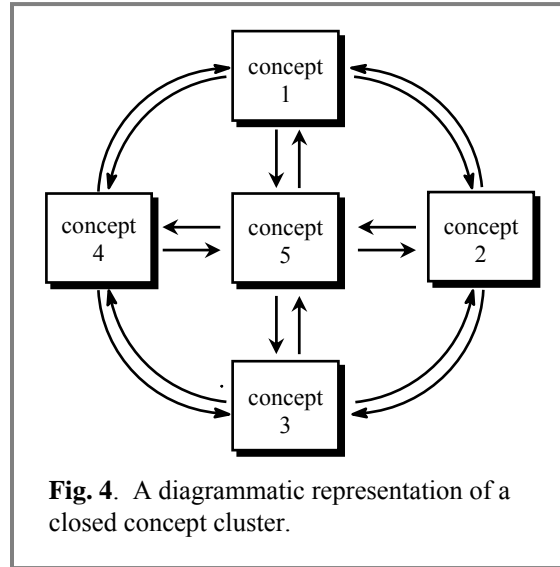


Fig. 4. A diagrammatic representation of a closed concept cluster.

### THE SATL TECHNIQUE

**Linear vs. Systemic Teaching.** The usual approach to teaching a subject involves arranging the associated concepts in a linear manner (Fig. 5A). For the sake of discussion, assume there are four (4) concepts to be taught. In the linear approach there may be several ways to approach teaching these four concepts in the example shown. The choice of the specific linear approach is often highly subjective and it may obscure relationships that students can understand. The SATL technique involves organizing the concepts associated with a subject to show the interrelationships among the concepts (Fig. 5B).

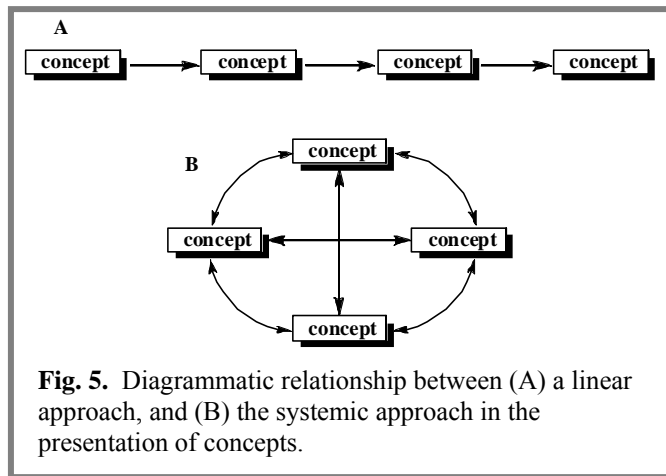
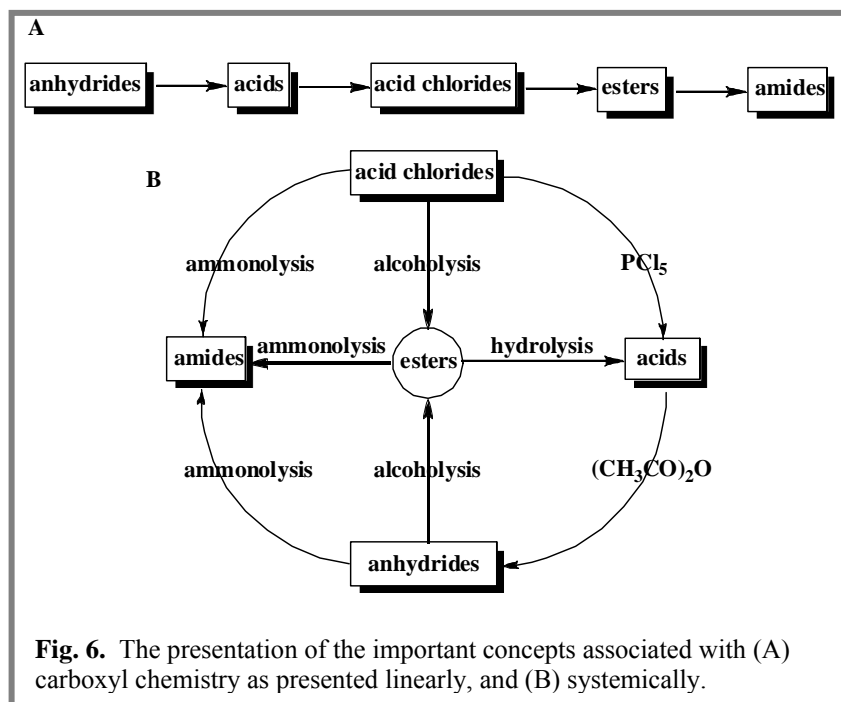


Fig. 5. Diagrammatic relationship between (A) a linear approach, and (B) the systemic approach in the presentation of concepts.

A diagrammatic representation of these two approaches to teaching is shown in Fig. 5.



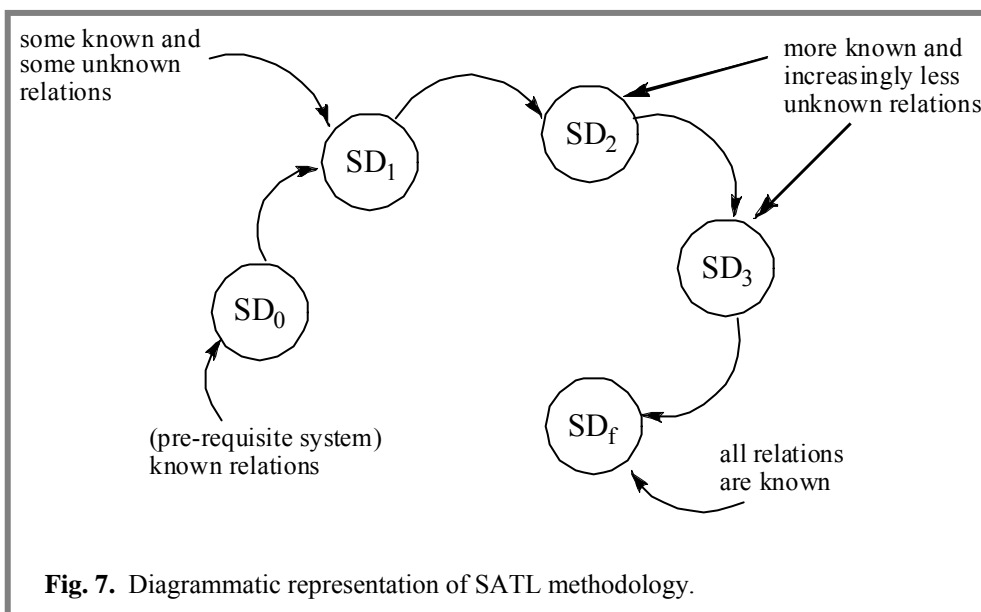
We introduce now the basic ideas of the systemic approach to teaching and learning. Although the SATL technique has been applied to a variety of subjects, we choose to use examples from chemistry, the subject in which we were trained. By

“systemic” we mean an arrangement of concepts or issues through interacting systems in which all relationships between concepts and issues are made explicit to the learner using a concept map-like representation. In contrast with the usual strategy of concept mapping, which involves establishing a static hierarchy of concepts, our systemic approach strives to create a more-or-less dynamic system of an evolving “closed system of concepts”—a concept cluster (Fig. 6B shows an example that stresses the interrelationships associated with the chemistry of organic acids). Further, our use of the term “systemics” stresses recognition of the *system* of concepts that form the cluster of concepts under consideration, and the dynamic evolution of the concept cluster in the hands of the teacher. Systemics means the creation of closed-cluster concept maps for the purposes of helping students learn; systemics is an instructor-oriented tool and, hence, requires teacher and student materials to be created about the closed-cluster concept map strategy. A more complete description for creating systemic diagrams appears in the next article.

Although we have produced and used a number of closed-cluster systemic maps on a variety of chemistry-oriented subjects, we illustrate the processes with a module in organic chemistry that was used in an experiment to establish (16) the efficacy of our approach.

**Operational Systemics.** Having established the underlying relationships between constructivist theory and concept maps with SATL ideas, we now turn to illustrate some of the details of how systemic diagrams are used in teaching. Imagine that a group of students studying organic chemistry are part way through the course having studied the hydrocarbons, alcohols, alkyl halides, aldehydes, and ketones and that they are ready to start their studies of carboxylic acids. The information to be learned could be organized into an appropriate systemic diagram (or, perhaps, it already exists as such) which we will call  $SD_0$ . In Ausubel's terms,  $SD_0$  contains the prior knowledge upon which the new knowledge will be attached. A new systemic diagram

can be started from an appropriate part of  $SD_0$  to incorporate a new relationship characteristic of carboxylic

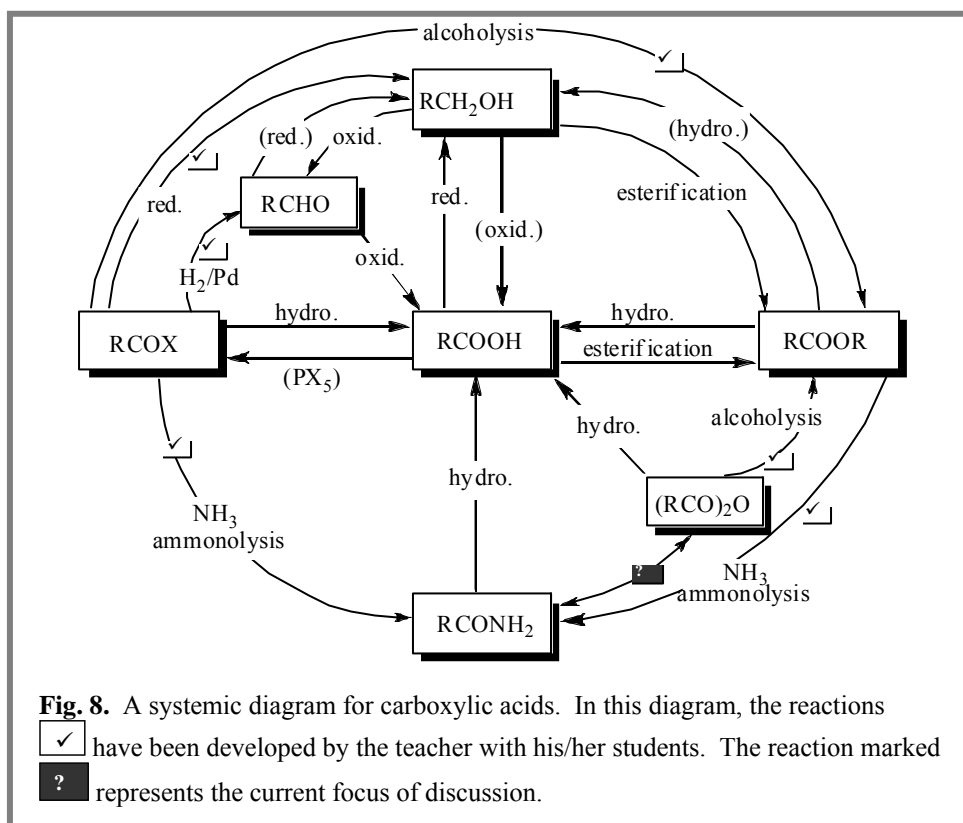


acids; call this "new" (or, beginning diagram)  $SD_1$ .  $SD_1$  can now be altered with another new characteristic relationship of carboxylic acids to form  $SD_2$ , and so on to  $SD_3$ ,  $SD_4$ , etc., to the final systemic diagram,  $SD_f$ .  $SD_f$  now becomes the prior knowledge for the next systemic



diagram. A diagrammatic representation of this evolutionary process to the final systemic diagram is shown in Fig. 7.

As an example, Fig. 8 is the *entire* systemic diagram for *all* of the reactions of carboxylic acids. At this point in the evolution of that systemic diagram, the relations indicated



by  have been developed by the teacher with his/her students whereas the symbol  represents the current focus for the classroom discussion. In the current example of the operational use of systemics, Fig. 8 represents *all* of the chemical relationships for the carboxylic acids that are to be taught in this class. [Note: Fig. 8 may not truly represent *all* the extant chemical relationships *known* for the carboxylic acids.] So, from the point of view of this example, Fig. 8 represents the content goals for this class as have been prepared by the teacher.

## **EVALUATION OF SYSTEMIC TECHNIQUES**

The efficacy of using the SATL method to help students learn chemistry has been studied using controlled experiments (16,17) in which the achievement of student learners exposed to SATL methods was compared with that of a similar cohort of students taught in the conventional linear manner. Students ( $n=429$ ) in six (6) secondary schools in the Cairo and Giza (Egypt) school districts who were studying organic chemistry were involved in this experiment.

The SATL intervention occurred over a two-week period and was focused on the chemistry of carboxylic acids which appeared in the middle of the standard curriculum after hydrocarbons, alcohols, aldehydes, and ketones, but before amines. Standard laboratory experiences were also included in the material used in this study. The control group ( $n=159$ ) was taught using the standard linear approach to the subject. A systemic-oriented module on carboxylic acids was created for this study and was used by the experimental group ( $n=270$ ).

All teaching and administrative personnel—thirty (30) people total—who had a legitimate interest in the students involved (Egyptian Ministry of Education represented by content experts; Educational Districts, represented by local inspectors; and Educational Zones, represented by General Inspectors). Four (4) teachers with 15-18 years of experience were involved in teaching with SATL materials, and eight (8) teachers with 20-26 years of experience taught the control group using standard linear-oriented materials. All personnel—teachers and administrators—attended an 18-hour training session; the teacher cohort attended the full workshop whereas the administrators attended only those sessions that pertained to their responsibilities.

The assessment strategy included a comparison of student scores on appropriate examinations as well as survey instruments and interviews that probed the affective domain. A

pre- and post-test strategy was employed; tests involved a mixture of question types—multiple choice, short answer, and completion of systemic diagrams. The tests were scored by the teachers using supplied answer keys.

Several important general points flow from this well-constructed and carefully conducted experiment. Both the control and the experimental classes (Table 1) exhibited similar pre-intervention mean scores for linear questions—those kinds of questions that are typically asked in courses taught by traditional methods. This result might not be unexpected, since both cohorts were taught the previous (prerequisite) content materials by traditional methods.

**Table 1** Student scores on tests by type of instructional approach

Instructional Approach	Group Type	Pre-Test Scores			Post-Test Scores		
		Means	Standard Deviation	Standard Error Mean	Means	Standard Deviation	Standard Error Mean
Linear	Control ( <i>n</i> = 159)	44.73	15.13	0.18	46.16	15.37	0.85
	Experimental ( <i>n</i> = 270)	37.11	18.84	0.51	91.32	13.72	0.31
Systemic	Control ( <i>n</i> = 159)	16.63	13.44	0.14	20.1	14.24	0.97
	Experimental ( <i>n</i> = 270)	12.05	11.42	0.12	82.88	14.56	0.75

Post-intervention mean test scores were higher for both groups of students, as might be expected for any learning environment. However, the mean scores for the experimental group were markedly higher than those for the control group. A similar pattern evolved for systemically-oriented questions and, perhaps as expected, the mean scores for the systemically-oriented questions were considerably more improved for the experimental group who were, of course,

taught from the systemic point of view. Recall that systemics stresses the acquisition of the higher order cognitive skills as defined by Bloom (18)(19).

Students who were taught by instructors using SATL techniques were more successful on the final examination than students who were taught linearly, success being defined as achieving at least 50% on the final examination; note that this definition of “success” is that commonly used in these school districts. By this measure, approximately 80% of the experimental group were successful, but only 10% of the control group reached this level of success.

The analyses of student survey data (paper and interviews) indicate a positive perception that SATL methods improved the students’ ability to view the chemistry of the experimental module from a more global perspective and preliminary results indicate that the SATL approach affected the way students approached the subsequent subjects in the course that were taught traditionally in the chemistry curriculum. Interview data suggest that many students applied the SATL techniques to their other studies. An interesting insight from teacher interviews expressed an opinion they could create systemic-oriented teaching materials in biology and physics, which they were also qualified to teach.

Similar demonstrable success in student achievement using SATL methods in other chemistry courses has been reported for the following subjects (see Table 2): aliphatic chemistry (21); (22); (23), aromatic chemistry (24); heterocyclic chemistry (25); (26);(27);analytical chemistry (28) and physical chemistry (29).

### **SYSTEMICS AND OTHER DISCIPLINES**

Although the successful application of systemics has been well demonstrated in the chemical sciences (Table 2), the literature contains reports of the successful use of SATL methods in linguistics (Arabic), mathematics, medical sciences, law, agricultural sciences, and

engineering; references to these works are all in Arabic and can be found at the SATL Central website (SATL website).

**Table 2: SATLC Materials in Chemistry**

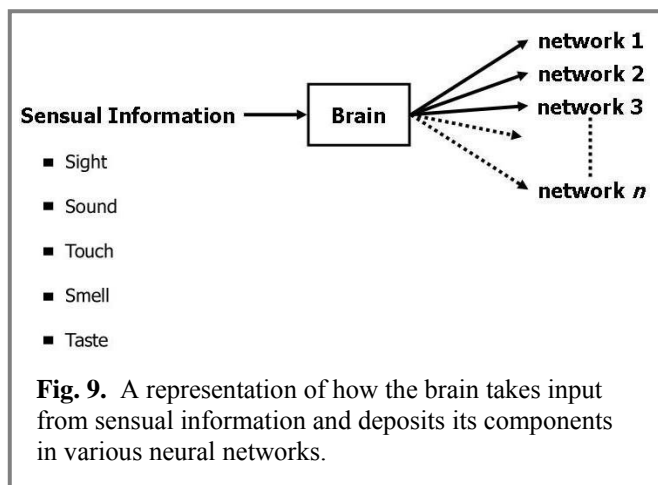
<b>Subject Matter</b>	<b>Student Level</b>	<b>Duration/Date</b>	<b>Presentation Venue</b>
A unit on Carboxylic acids and their derivatives (17)		9 Lessons Two Weeks March 1998	Presented at the 15 <sup>th</sup> ICCE, Cairo, Egypt, August 1998
A Unit on Classification of Elements (20)		15 Lessons Three Weeks October 2002	Presented at the 3 <sup>rd</sup> Arab Conference on SATL, April 2003
A Textbook entitled "Aliphatic Chemistry" (21,22,23)	University Level -Pre-Pharmacy -Second year, Faculty of Science	One Semester Course 16 Lectures, 32 hours During the academic years 1998/1999, 1999/2000, 2000/2001	Presented at the 16 <sup>th</sup> ICCE, Budapest, Hungary, August 2000
A Textbook entitled "Heterocyclic Chemistry" (25, 26,27)	-Third Year, Faculty of Science	10 Lectures, 20 hours During the academic years 1999/2000, 2000/2001	Presented at the 7 <sup>th</sup> ISICHC, Alex., Egypt, March 2000. 9 <sup>th</sup> ISICHC Sharm El-sheikh, Egypt, December 2004
A Unit on Benign Analysis (28)	-First Year Faculty of Science	One Semester Lab Course, 24 hours (2 hours/week) During academic year 2001-2002	Presented at the 17 <sup>th</sup> ICCE, Beijing, August 2002
A Textbook entitled "Aromatic Chemistry" (24)	-Second Year Faculty of Science	One Semester course (16 lectures, 32 hours) During the academic year 2000/2001	Presented at the Malta 3 <sup>rd</sup> Conference on Frontiers of Chemistry Teaching and Research in the Middle East, Istanbul, December 2007

<sup>a</sup> See also (Ref. 34)

## BRAIN FUNCTION

The demonstrable success of SATL methods and constructivist theory can be understood in terms of our current understanding of how the brain works. For the past several decades, cognitive psychologists and physical scientists have developed a variety of techniques to map the functioning brain as it performs various tasks (30); (31); (32); (33). Non evasive probes that have been employed in establishing brain behavior include, computed tomography (CT), computer axial tomography (CAT), magnetic resonance imaging (MRI), functional magnetic imaging (fMRI), positron emission tomography (PET), single-photon emission computer tomography (SECT), diffuse optical imaging (DOI), event related optical signal (EROS), and electroencephalograms. Using such techniques, the functions of the different areas of the brain have been identified. The term “area” does not necessarily imply contiguous parts of the brain; these parts may be connected through common nodes. Perhaps a better descriptor is a “network.” One current view of the human brain is that it has a modular organization consisting

of identifiable component processes that participate in the generation of a cognitive state. The five senses—sight, smell, touch, hearing, and taste—are the gateways to the brain (Fig. 9). Our view of the world is *constructed* by our brain, as it interprets the signals from these

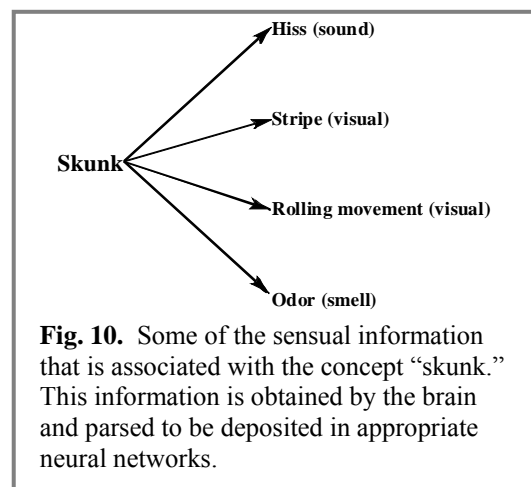


**Fig. 9.** A representation of how the brain takes input from sensual information and deposits its components in various neural networks.

five senses coming through the gateways. Although much is known about the details of how the chemical and electrical signals from the five senses are created and pass into the various areas of the brain, these details are not important for our purposes here. The totality of these methods and

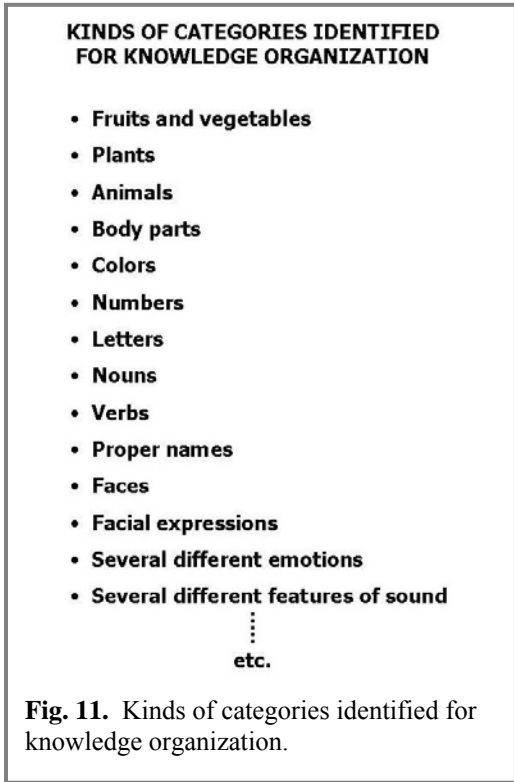
the results of other experiments produce a representation of the major parts of the brain as well as detailed information on how these are believed to interact with each other.

Our current knowledge produces the following model of how the brain works—how it does what it does. The information input in the brain is *not* stored in a single part of the brain. The brain does *not* store information like an encyclopedia—to be retrieved “as a complete unit on demand.” Rather, the data suggest that information is distributed in different networks of neurons, which are the basic elements of brain activity (Fig. 9). Thus, when someone perceives a *skunk*, all the sensual characteristics of the skunk—the hiss, the stripe, the rolling movement, the odor, etc., are stored in different, but appropriate neuron networks (Fig. 10). Retrieving the concept of the skunk from memory corresponds to the interaction of all the specialized networks that contain the skunk-related characteristics, which are then reassembled by the brain into the memory as the skunk concept.



**Fig. 10.** Some of the sensual information that is associated with the concept “skunk.” This information is obtained by the brain and parsed to be deposited in appropriate neural networks.

The human mind creates a number of categories for the kinds of information it stores. About 20 have been identified and there are probably a very large number more (Fig. 11). Notice how the categories listed have strong components associated with the senses, because these are the only signals that reach the brain. So, it appears that his kind of information storage in the brain is genetically encoded since humans have only five senses with which to learn about the world in which they live. From one point of view,



**Fig. 11.** Kinds of categories identified for knowledge organization.

it

the human brain is automatically (genetically hard-wired) a knowledge-seeking entity. The knowledge is that associated with the world in which the brain exists.

The distributed information is stored in appropriate networks of neurons that exist in many parts of the brain. The networks are probably interconnected so that the retrieval of the distributed information can start from many places. Many experiments indicate that information is stored in distributed forms, which is then reassembled or reconstructed upon retrieval. It must be noted that “reassembled” and “reconstructed” represent processes that are synonymous with the constructivist mode of learning. Thus, it appears that the sum total of our current knowledge about learning is consonant with the general precepts of constructivism. We “automatically” deconstruct and construct concepts when we learn deeply so it seems logical that teachers should attempt to mimic that process, which is the fundamental basis for the SATL techniques.



## CONCLUSION

In this review of the current status of the Systemic Approach to Teaching and Learning (SATL) we have described its relationship to constructivist ideas of learning. Examples of the application of these techniques are detailed for chemistry as is experimental data derived from a study of the efficacy of the method in teaching at the secondary level in Egyptian schools. The modern view of brain function is also linked to constructivist ideas.

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## ASSESSMENT OF THE DIFFICULT AREAS OF THE SENIOR SECONDARY SCHOOL 2 (TWO) CHEMISTRY SYLLABUS OF THE NIGERIA SCIENCE CURRICULUM

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### ABSTRACT

The senior secondary two chemistry course content of the Nigerian science curriculum was assessed using 10 (ten) selected secondary schools in North Central Nigeria, to determine areas of difficulty, magnitude and reasons for such perceived difficulty. Correlation between the students' perceived difficulty and their achievement in a test and the relationship between the students' sex and their perceptions of difficulties were also examined using a difficult rating scale questionnaire and a chemistry achievement test. Percentage mean score, mean difficulty indices, person-product-moment correlation and the t-test methods were used for the analysis of the data collected. A total of 10 (ten) out of the 24 (twenty-four) topics identified were perceived as difficult. There was no significant relationship between students' perceived difficulty and their achievement. Reasons given for the perceived difficulty included unfamiliarity with the ideas, confusing language, ideas too demanding, insufficient explanation and practical work, topics too mathematical and lack of interest among both sexes. Based on these findings, a critical re-assessment of the curriculum was advocated, bearing in mind the cognitive abilities of /and chemistry (science) background of the students. Proper training and re-training (refresher) of teachers was recommended so as to ensure that teaching staff are qualified. Authors of chemistry textbooks should consider the cognitive levels of students of the different levels for choice of suitable vocabulary (language). Teachers should re-examine and evaluate their present teaching strategies so as to be effective and should stop using abstract terms or concepts in the class. Practical work should be emphasized for the acquisition of laboratory skills. The government/proprietors should give priority to equipping the laboratories and improving the teaching and learning environment. Students need counseling, encouragement and enlightenment in order to motivate them in the study of Chemistry. (AJCE, 1(1), January 2011)

## **INTRODUCTION**

Chemistry is one of the science subjects upon which technological break-through is built and is the pivot on which the wheel of science rotates. Chemistry is very important and helpful in fields such as medicine, agriculture, transportation, housing, industries, etc. Life is made more meaningful with chemical product such as drugs, cosmetics, paints, soap, fertilizers etc. In addition, various careers exists in chemistry in the health sector, food processing industries, extractive industries, petroleum and petrochemical industries among others (1).

Nigeria is a developing nation and the importance of chemistry for such a nation cannot be over emphasized. This is in line with the assertion that the prestige and political power of any nation reside in its level of scientific activities (2).

The United States of American had undertaken reforms in its science curriculum development (3) which led to Chemical Bond Approach (CBA), Chemical Education Material Study (CHEM STUDY) and the Physical Science Study Committee (PSSC) in conjunction with other physical sciences. Similar curricular reforms had also been carried out in other countries (4). The successes of these reforms in Britain and United States are often linked with the curriculum packages that had evolved. These packages adopted different approaches, and emphasis was laid on content and how the content could be commensurate with the cognitive level of the students.

In Nigeria, the need to re-examine both what to teach in science and how to teach it led both institutional and professional bodies to identify themselves with national efforts toward curriculum reform in sciences (5). For example, the Science Teachers Association of Nigeria (STAN) had taken initiative in the science curriculum development. Thus in 1968, the federal ministry of education and the Comparative Education Study and Adaptation Centre (CESAC),

set up curriculum development committee in each of the following subjects biology, chemistry and physics. These bodies, including the National Education and Research Council (NERC) made immense contribution toward improving science education. All these have not only modernized science teaching, but stimulated interest among Nigerian youths, science educators and government in science related courses. Thus the government tried to popularizes and encourage the teaching of sciences in schools through positive incentives like giving priority to science courses in scholarship and in-service awards, building and commissioning of science equipment production centers, special science allowances to science teachers and the building of universities of technology, colleges and science schools.

It is worthy to note that members of STAN still meet from time to time to review and asses progress made so far, and organize workshops, seminars, conferences, etc to enlighten members (science teachers especially) about new development and research studies carried out in the sciences and science education in general.

### **STATEMENTS OF THE PROBLEMS/PURPOSE OF THE STUDY**

The crux of the matter is that most of the few students who choose to offer sciences in our secondary schools are noted for having problems learning the sciences especially chemistry since its introduction (6). Poor performance, according to Jegede and Okebukola (7), is unhealthy to a nation whose aversed goal is to make significant changes and advancements in science and technology. To Eke (8), poor performance does not connote abnormality in development, but involves those who probably could perform better. Though caused by many variables such as teacher and students characteristics, examination patterns and science equipment, poor performance in chemistry is a pointer to the fact that students have difficulty in

learning and mastering the content and applying these when they are under examination conditions.

Though several factors have been identified for students' poor performance in the sciences and efforts made toward tackling some during seminars, conferences and workshops, the students' performance is still not encouraging as expected. The identification of areas of difficulty in the chemistry and hence, science syllabus is therefore important. This study was set to identify those areas that pose some problems or difficulties to students in the senior secondary 2 (two) chemistry syllabus in Nigeria.

### **RESEARCH DESIGN, POPULATION AND SAMPLING TECHNIQUE**

This research was a case study survey designed to identify students' perceived difficulties in the learning of the senior secondary two chemistry in secondary schools of Plateau State, north central Nigeria. A case study, according to Piwuna (9), is the study of the characteristics of an individual, class, liquid, school or community.

The population composed of students offering chemistry as one of the subjects at the senior secondary school level. The schools cut across voluntary agency and government-owned secondary schools and colleges in the state. The students in the final class, senior secondary three, were used because they had completed the senior secondary two and were therefore, familiar with the course content.

The research sample used was made up of three hundred students drawn from 10 (ten) schools from three local government areas of Plateau state. The student sample included students of mixed ability and age. Apart from categorizing the students into males and females, there was no other grouping of any kind.

A total of 10 (ten) secondary schools were selected from the over 200 secondary schools in the four local government areas used for the study using the random sampling technique. The schools are those that offered sciences especially chemistry at the senior secondary school certificate level.

Thirty students were selected from each of the ten schools by the random sampling method to take part in the study.

## **RESEARCH INSTRUMENTS**

Two research instruments were used for the study. These were:

- i. Difficulty rating scale
- ii. Chemistry achievement test (CAT) designed by the researcher.

The difficulty rating scale consisted of two parts, the background information which seeks information about the students like name of school, sex, age, etc, and a two-part checklist. In the checklist, the senior secondary two chemistry topics were listed. Each topic was followed by columns where students were to indicate the magnitude of its difficulty by ticking: Not difficult [1], Slightly difficult [2], Undecided [3], Decided [4], Very difficult [5]. The students also indicated the reasons for the difficulty in columns provided by ticking. The topics were numbered accordingly and included: Periodicity of elements [1], Stoichiometry of chemical reactions [2], Volumetric analysis [3], Types of chemicals [4], Redox reactions [5], Balancing of redox reactions [6], Electrode potential and electrochemical cells [7], Preferential discharge of ions [8], Laws of electrolysis [9], Energy and chemical reactions [10], Chemical equilibrium in reversible reactions [11], Water harness and treatment [12], Solubility [13], Hydrogen preparation, properties and uses [14], Oxygen preparation, properties, compounds and use [15],

Chlorine and its compounds [16], Sulphur and its compounds [17], Nitrogen and its compounds [18], IUPAC nomenclature of organic compounds [19], Alkenes preparation properties and use [20], Alkenes preparation, properties and uses [21], Alkynes preparation, properties and uses [22], Alcohol preparation, properties and uses [23], Rates of chemical reactions [24].

The CAT consisted of a 30-item objective test covering the entire senior secondary two chemistry course content constructed by the researcher. Each item consisted of five options lettered A-E out of which only one was the correct and acceptable answer. Both Face and Content validity of the instruments were carried out with professional chemical educators participating.

Data obtained from respondents were analyzed by calculating the mean difficulty index for each topic.

## **PRESENTATION OF DATA**

The data were treated to descriptive analysis and the difficult indices computed for the twenty-four topics. This was to determine the areas of difficulty. The student scores in the achievement test was also computed and presented.

The raw scores for difficult topics for female and male students are shown in Tables 1 and 2 respectively. Table 3 shows the percentage difficulties of the topics while the percentage scores and difficulty indices of the difficult topics are presented in Table 4. The students' reasons for perceived difficulty in the subject and the reasons for perceived topic difficulty in chemistry in percentages are shown in Tables 5 and 6 respectively. All the tables are in the appendix.



## DISCUSSION OF RESULTS

The results of this research revealed that the secondary school chemistry students considered some topics of the senior secondary two chemistry course content difficult to learn. These topics included;

*Types of chemical reactions, Redox reactions, Balancing redox reactions, Electrode potential and electrochemical cells, Laws of electrolysis, Chemical equilibrium, Reversible reactions, Solubility, Sulfur and its compound, IUPAC nomenclature of organic compounds, alkynes*

The identification of these topics were similar to the works of Folayan (10), Adisa (11), Asom (12) and Adzape (13), who identified certain topics in the chemistry syllabus as difficult to students. This research, however, found that only a few topics were considered difficult compared to the total course content for senior secondary two. This could be due to a more careful curriculum plan. The students did not perform well in the achievement test, a reverse of what was expected since they did not experience too much difficult with the topics. The low performance may be attributed to the fact that they were not informed in advance to prepare for the test. Tables 4,5 and 6 showed that there was no significant relationship between the students' perceived difficulties in learning the chemistry course content and their achievement, a finding similar to that of Ochima (14), but different from those of Piwuna (9) and Akpan (15).

While the male students considered certain topics such as balancing of redox reactions, laws of electrolysis, sulphur and its compounds as difficult, the females did not. The female students considered topics such as types of chemical reactions, preferential discharge of ions, energy and chemical reactions, chemical equilibrium in reversible reactions and nitrogen and its compounds as difficult which the males did not. Both considered some topics difficult.

It was discovered that most female chemistry teachers were unable to teach the topics, the respondents claimed; usually they do not want to spend extra time after school for practical and avoid topics that are mathematical.

Ranking first is the lack of practical work as teachers are reluctant in conducting practical works. This agrees with Ajeyalemi (16) and Adamolekun (17). Lack of practical work can also be attributed to lack of the basic facilities in the schools such as laboratories. Abdullahi (2), Piwuna (9) and Adeyegbe (18) observed that insufficient explanation by the teachers can be attributed to misconception by the teachers of some topics, failure to possess a sound academic and professional knowledge of the subject, the use of wrong methods and lack of interest in the job. The above all point to the teacher as one of the factors contributing to student's perceived difficulty in learning chemistry.

The cognitive demand of the course content came up as another major reason for student's perceived difficulty in chemistry. Many of the general principles have mathematical bases and most of the concepts are abstract. These findings agree with those of Akinmade and Adisa (19), Akpan (20) and Adzape (13). As Okoli (21) noted, most of the topics in the O' level chemistry syllabus are for students with above average ability, while some are broad, uninteresting and boring.

The research identified the language and vocabulary of chemistry with the attendant confusion of names especially from the IUPAC nomenclature as one of the factors responsible for the difficulty in learning chemistry.

This finding agrees with Adzape (13) and Akpan (22) and Akpan's (15) finding. Akpan (15) has remarked that the language difficulty has contributed to students declining performance in chemistry examination.

## **IMPLICATIONS OF THE FINDINGS AND RECOMMEDATIONS**

The researchers in consonant with Adeyegbe (23), Akpan (15) and Adzape (13) noted that most of the topics perceived as difficult by the students are abstract in nature. A careful method of approach is therefore required to teach the inherent principles of such topics. The researchers recommend that examples rather than precepts should be used. Chemistry teachers should utilize to students' advantages examples which abound around and among us. The use of local examples and teaching aids to illustrate principles and concepts, especially in practical works, needs no further analysis or emphasis. This also reduces costs. The abstract nature of the subject can further be reduced when teachers avoid using highly technical words except where unavoidable as when considering IUPAC names. Chemistry teachers should ensure that the students have adequate background knowledge of each topic. As suggested by Akpan (15), teachers should use reagents which in reactions, result in very sharp but contrasting colorful products. Such would increase the student's interest in the subject. Practical work should be emphasized and the students should be made to acquire laboratory skills as this will equip them better.

A challenge is hereby thrown to authors and curriculum planners. Authors of chemistry texts and other materials should take into account the level of cognition of the students at the different levels and come up with indigenous textbooks commensurate with the secondary level chemistry education. This will make it possible for local examples to be identified and incorporated into these textbooks. Moreover, if the textbook experiences are investigation oriented, it will generate greater interests in these areas and direct attention to challenges for research and exposition.

Curriculum planners on their part should ensure that the chemistry curriculum is made purposeful enough to awaken the inner resources of our students (youths) and not just a mere device for mass production. It should provoke educational experiences and be sensitive to higher needs of the individuals (students).

The curriculum- however well planned, developed and interpreted-will come far short of our hopes unless it is applied by teachers who are themselves the product of its philosophy. Science teachers should be professionally screened and trained so as to equip them for the effective performance of their duties.

Government and proprietors should increase teacher's salaries and incentives especially to science teachers in the form of science allowance, reducing the burden on teachers by supplying schools with the basic chemistry equipment. This, and the employment of laboratory technicians, will curb the frustrations teachers face and improve on students' understanding. Above all, chemistry teachers in the secondary schools should re-examine and evaluate their teaching strategies, and resort to modern and effective strategies. Such teachers should develop not only a new set of attitudes, but also new professional skills and habits.

With positive attitude, students will choose to study chemistry because of the interest they have. They need to have a good background in chemistry and science in general. Scientific concepts and processes would not appear strange to them if they are introduced to them in the primary school. Our industries can make toys that can impact toddling age to bring science closer to children and make it real to their life. Finally there is a need for the counseling of students who opt for chemistry right from their senior secondary one. They need to know the relevance of the subject, how to study it and the attitude necessary. They need to know that a lot is expected

from them in terms of hard work, dedication and even resources for successful completion of the course (study).

## CONCLUSION

This study revealed that there are no significant differences between male and female students in the perceptions of content difficulties, reasons for perceived difficulties and their achievement in a test. One may expect such a result as there is usually no sex discrimination in the admission exercises into the secondary schools. The low performance of the students on the achievement test may be due to the fact that they did not read (prepare) for such a test as they were taken unaware, not necessarily due to the perceived difficult topics.

Though this study has found out that there is no significant relationship between students' perceived difficulties and their achievement, it should be noted that statistical significance is not necessarily the same as practical significance.

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**Appendix**

Table 1: Raw scores for difficult topics (female students only)

TOPIC	ND	SD	U	D	VD	TOTAL	N	X
1	28	58	81	76	80	323	119	2.71
2	31	64	54	88	80	317	119	2.66
3	34	46	75	84	80	319	119	2.68
4	10	38	84	148	125	405	119	3.40
5	07	44	60	172	135	418	118	3.50
6	22	56	81	92	90	341	109	3.88
7	20	36	66	136	75	333	119	3.89
8	19	48	75	120	105	367	119	3.08
9	27	68	84	72	60	311	119	2.61
10	18	46	57	120	120	361	114	3.17
11	21	50	27	132	155	385	119	3.23
12	20	62	81	76	110	349	119	2.93
13	10	38	105	112	125	390	117	3.33
14	38	62	27	88	95	310	119	2.60
15	27	76	72	72	60	307	119	2.58
16	30	82	57	68	55	292	118	2.47
17	23	58	31	88	90	340	119	2.86
18	15	48	90	140	75	368	119	3.09
19	13	42	99	116	115	385	119	3.23
20	35	62	48	68	90	323	117	2.76
21	23	72	60	72	110	337	119	2.83
22	15	44	75	116	140	390	119	2.28
23	25	80	57	80	70	312	118	2.64
24	31	54	87	72	70	314	119	2.64

Table 2: Raw scores for difficult topics for male students

TOPIC	ND	SD	U	D	VD	TOTAL	N	X
1	59	92	33	96	130	410	166	2.47
2	36	114	30	112	175	465	166	3.80
3	34	122	105	68	50	379	155	2.41
4	35	98	75	144	105	457	166	2.75
5	32	52	78	160	210	532	166	3.20
6	30	24	81	172	260	567	164	3.46
7	28	66	63	108	250	515	159	3.24
8	57	70	72	72	160	431	166	2.60
9	18	40	60	204	285	607	166	3.66
10	44	112	84	72	100	412	66	2.48
11	30	88	102	128	130	478	66	2.88
12	40	106	120	68	80	414	155	2.49
13	41	46	33	160	200	480	166	3.09
14	63	78	33	144	85	403	166	2.43
15	44	98	21	112	190	465	166	2.80
16	60	62	42	168	85	417	164	2.54
17	35	40	105	168	170	518	166	3.12
18	38	90	51	92	190	461	161	2.86
19	41	48	45	132	265	531	166	3.19
20	45	88	42	112	145	432	160	2.70
21	42	84	69	164	90	449	166	2.70
22	30	72	54	200	160	516	166	3.11
23	47	54	57	104	235	497	166	2.99
24	58	100	06	116	135	415	166	2.50

Table 3: Percentage difficulties of topics

LEVEL OF DIFFICULTY	number	percentage	average difficulty indices
Difficult topics	10	41.67	3.16
Non-Difficult topics	14	58.33	2.69
<b>Total</b>	<b>24</b>	<b>100</b>	

Table 4: Percentage scores and difficulty indices of difficult topics

topic	% pass in achievement	% difficulty index
Type of chemical reactions	30	60
Redox reactions	35	67
Balancing of redox reactions	16	64
Electrode potentials and electrochemical cells	20	63
laws of electrolysis	20	64
Chemical equilibrium in reversible reactions	31	60
Solubility	27	64
Sulphur and its compounds	23	60
IUPAC nomenclature of organic compounds	26	64
Alkynes	36	64

Table 5: Student's reasons for perceived difficulty in chemistry in percentage

REASONS		PERCENTAGE	TOTAL
Teacher-related factors	1	12	33.99
	2	9.55	
	3	12.44	
Curriculum-related factors	4	8.60	53.44
	5	10.10	
	6	9.10	
	7	10.10	
	8	9.34	
	9	6.20	
Student-related factors	10	6.64	12.58
	11	5.94	

Table 6: Reasons for perceived topic difficulty in chemistry in percentage

	TOPIC	REASONS (%)										
		1	2	3	4	5	6	7	8	9	10	11
4	Types of chemical reactions	27	4.5	23	7.6	5.6	9.7	1.5	10.7	1.5	0.01	7.6
5	Redox reactions	10.8	19.1	3.3	16.1	13.6	7.9	15.5	5.3	0.03	1.6	6.3
6	Balancing redox reactions	18.5	14.6	4.2	5.9	13.6	16.7	8.7	4.8	5.2	0.03	7.3
7	Electrode potential and electrochemistry	15.1	12.1	18.7	10.9	6.2	4.7	14.4	4.3	3.9	3.9	5.8
9	Laws of electrolysis	9.9	6.7	17.0	7.7	8.6	5.4	6.1	9.6	18.9	3.8	6.1
11	Chemical equilibrium	17.3	13.1	8.0	8.8	7.1	8.0	11.8	7.2	4.6	7.1	6.8
13	Solubility	13.8	10.6	12.6	4.8	11.2	7.8	10.3	4.8	14.0	4.6	5.1
17	Sulphur and its compounds	8.9	5.7	11.7	8.5	16.7	6.3	6.0	17.0	1.8	9.9	7.4
19	IUPAC nomenclature of organic compounds	12.9	7.6	3.6	14.3	10.3	4.9	14.9	12.9	3.6	8.3	6.3
22	Alkynes	10.9	6.8	13.3	6.8	8.9	12.1	15.3	8.5	2.4	7.6	6.8



## **THE SYSTEMIC APPROACH TO TEACHING AND LEARNING [SATL]: OPERATIONAL STEPS FOR BUILDING TEACHING UNITS**

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### **ABSTRACT**

Systemic diagrams are the key to creating units of study for the method described as the Systemic Approach to Teaching and Learning (SATL). Here we present a detailed description of the generation of systemics. The general approach is first discussed to establish the basic ideas of SATL. The general method is then specifically applied to a portion of the aromatic chemistry of benzene and its simpler derivatives. Finally, examples of SATL-oriented questions for student assessment are presented. [AJCE, 1(1), January 2011]

## INTRODUCTION

In a previous paper (1) we have described the intellectual antecedents of the Systemic Approach to Teaching and Learning (SATL) techniques, namely, the constructivist theory (2), and concept maps (3) as well as our observation that a part of the success of the methods appears to mimic the current ideas of general brain function. Here we present the details of constructing and using systemic units for teaching and learning.

The key teaching device in the SATL technique is the Systemic Diagram (SD) which is a two-dimensional representation of the concepts that are to be taught to, or learned by the students in a class. As we described earlier (1), a systemic diagram can be thought of as a “closed concept map cluster” (Fig. 1). The person (teacher) who created the Systemic Diagram (Fig. 1B) has decided that not all of the concepts 1-6 displayed in Fig. 1A could be effectively incorporated in the Systemic Diagram, Fig. 1B. Apparently concept 4 will be picked up in another systemic diagram when it will, ultimately, be reunited with the other concepts. The minor excursion into creating a systemic diagram illustrates the flexibility of creating systemic diagrams.

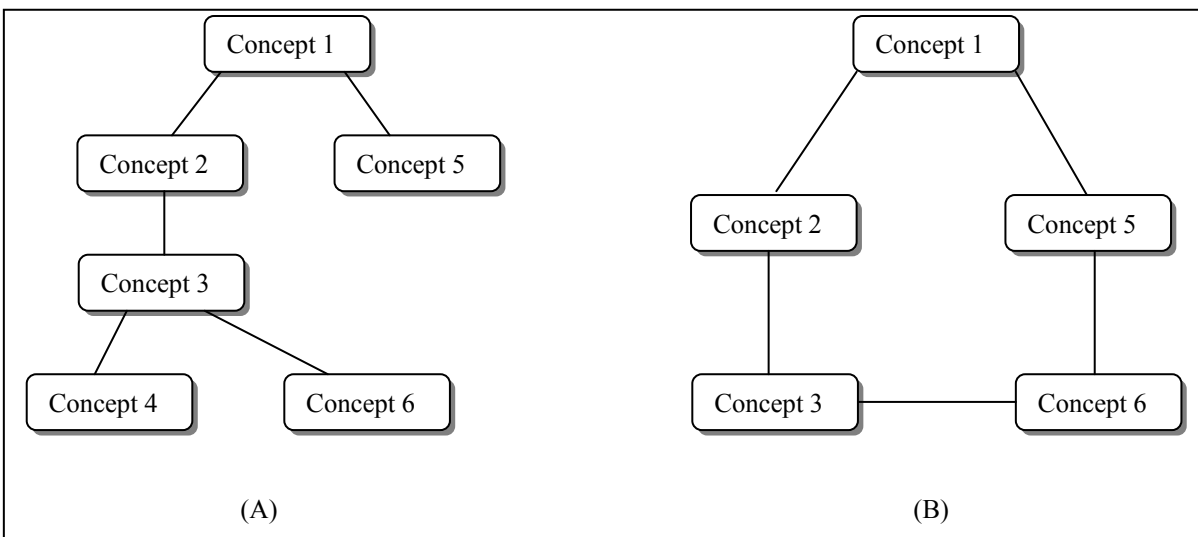


Fig. 1. A comparison of a concept map (A) and a systemic diagram (B).

Any unit to be taught using SATL methods involves the building of a systemic diagram ( $SD_0$ ) that has been determined as the starting point of the unit;  $SD_0$  incorporates the prerequisite concepts. Recall that Ausubel has suggested (2) that, in order to teach effectively, a teacher should start with what the students know and build upon this. The  $SD_0$  unit assures that all students will have the same starting point as they progress through the entire set of systemic diagrams. The unit ends with a final systemic diagram ( $SD_f$ ) in which all the relationships between concepts in the unit that have been taught to the student are known (Fig. 2). From  $SD_0$  through  $SD_f$  we encounter several smaller systemics with known and unknown relationships ( $SD_1, SD_2$ , etc.).

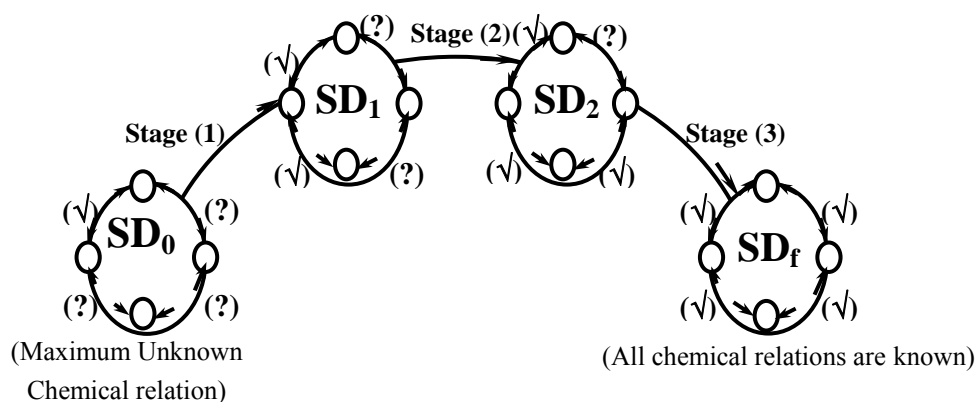


Fig. 2. Systemic teaching strategy

### BUILDING UNITS

The strategy of building SATL units is to convert the linearly based approach most often used to teach chemistry (and other subjects) into systemically-based units according to the following process;

1. The general systemic aims and the operational objectives for the unit should be defined.
2. The prerequisites needed for teaching the unit from previous studies (concepts, facts and skills) should be tabulated into a list.

3. The organization of the linearly-based list of materials (see step 2 above) into concepts, facts, laws, relations, skills, and affective issues should be established.
4. Draw a diagram (Fig. 3) illustrating linear relations among the concepts collected in step 3 above.

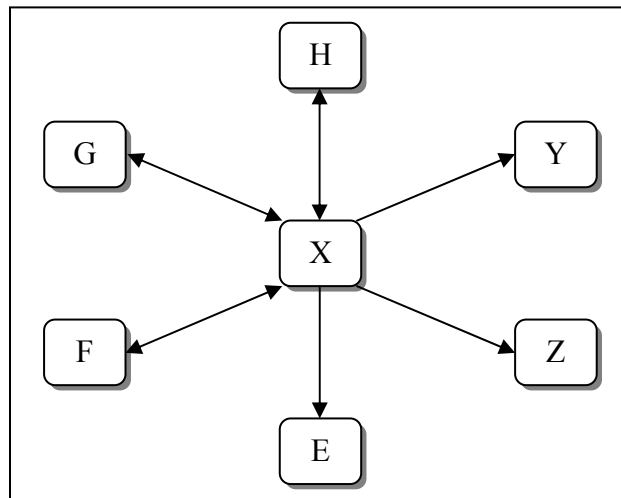


Fig 3. Linear relations between concepts

Consider the concepts X, Y, Z, E, F, G, and H that are contained in the teaching unit in question with its relevant facts and skills etc. Generally these concepts would be addressed linearly as shown in Fig. 3. We put a check ( $\checkmark$ ) on the relationships that are known (by the student) from previous studies, see Fig. 4. In this example, assume the linear relations (X-E), (X-Z), (X-Y) are known to the students from previous work, then the remaining linear relations (X-F), (X-G), and (X-H) are unknown to the student and are indicated by the question mark symbol (Fig. 4). In other words, the student knows the checked ( $\checkmark$ ) relationships and the point of the unit work is to learn the “unknown” (?) relationships. So the diagram in Fig. 3 will be modified as shown in Fig. 4.

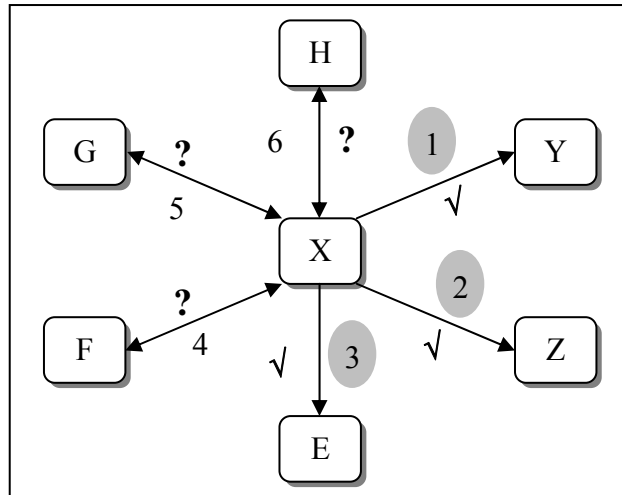


Fig. 4. Showing linear relations between concepts after defining the known from the unknown ones.

Notice in Fig. 4 that linear relations (1-3) are known and are indicated by the sign (✓), and the heads of arrows are defined ( $\rightarrow$ ), those “known relationships: represent the previous knowledge upon which the systemic diagram will be built. In other words, these relationships are assured or known to be within the knowledge structure of the students who will learn from systemics. The relationships (4-6) are undefined and indicated by the sign (?) and the heads of arrows are not defined ( $\leftrightarrow$ ); these represent the new knowledge that is to be learned by the students using this systemic diagram. Fig. 4 is modified to a systemic diagram by adding relationships between the concepts (H-Y), (Y-Z), (Z-E), (E-F), (F-G), and (G-H) (if such exist) which are indicated by the numbers 7-12; the result is shown on Fig. 5 and is identified as SD<sub>0</sub>.

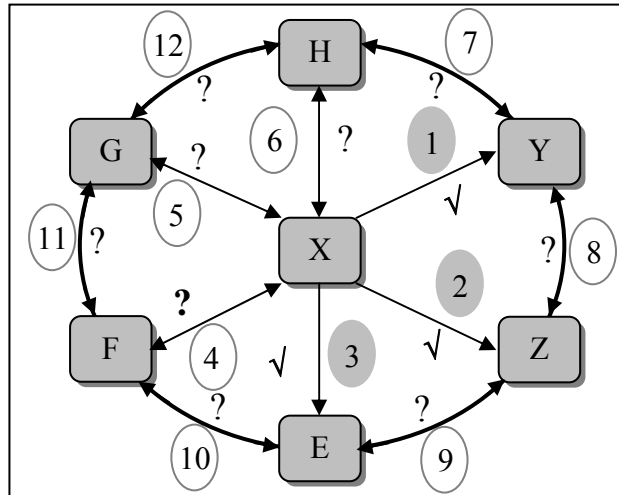


Fig. 5. The systemic diagram derived from Fig. 4. using the process described in the text.

The systemic diagram,  $SD_0$  (Fig. 5) has the following features:

- Because the relationships (1-3) are known the heads of arrows are defined ( $\rightarrow$ ) and the relationships are indicated by the check mark ( $\checkmark$ ).
- The known relationship between two concepts may go in both directions as indicated by double-headed arrows ( $\leftrightarrow$ ), but, to simplify in this case, we consider the relationships between concepts to have one direction ( $\rightarrow$ ).
- The relationships from 4-12 are not yet defined and are indicated by the question mark (?) and the double-headed arrows ( $\leftrightarrow$ ). These will be refined during the study of the unit.
- The systemic diagram shown as Fig. 5 is called the starting systemic diagram ( $SD_0$ ) because it contains relationships 1, 2, and 3 that are previously known to the student.

In the scenario for teaching this unit we start by teaching the relationships (7, 8, and 9), then all relationships are known to the student.

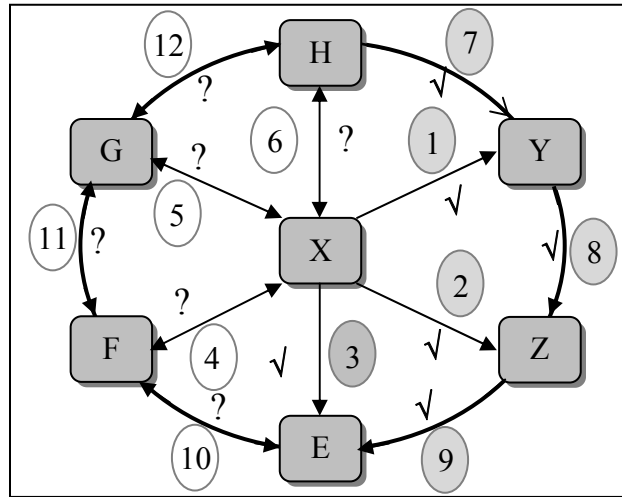


Fig. 6 (SD<sub>1</sub>)

In the systemic diagram, SD<sub>1</sub> (Fig. 6) the relationships 7, 8, and 9 have become defined—known by the student—and the arrow directions determined (→), but the remaining relationships, 4, 5, 6, 10, 11, and 12, are still unknown to the students and will be defined later during the study of the remaining parts of the unit. The student in the first stage of this study of unit has identified the relationships 7, 8, and 9; connecting them with the formerly studied relationships 1, 2, 3 and those that will be studied in the remaining parts of the unit.

In this stage of the study of this unit we can ask the students to build the systemic diagrams showing the relations between the concepts of X, Y, Z, and E during the systemic assessment.

In the next stage of the study, the student can study the relationships 4, 5, 10, and 11 and add them to SD<sub>1</sub>, (Fig. 6), to obtain SD<sub>2</sub>, (Fig. 7). In this systemic diagram all the relationships became known except 6 and 12, which will be identified in the later stage of the study of this unit. At this stage of the study, the student could study the relationships of 4, 5, 10, and 11 in view of the previously studied relationships followed by those that will be studied, namely, 6 and

12. Finally, the student can build several systemic diagrams showing the systemic relations in the systemic assessment (*vide infra*).

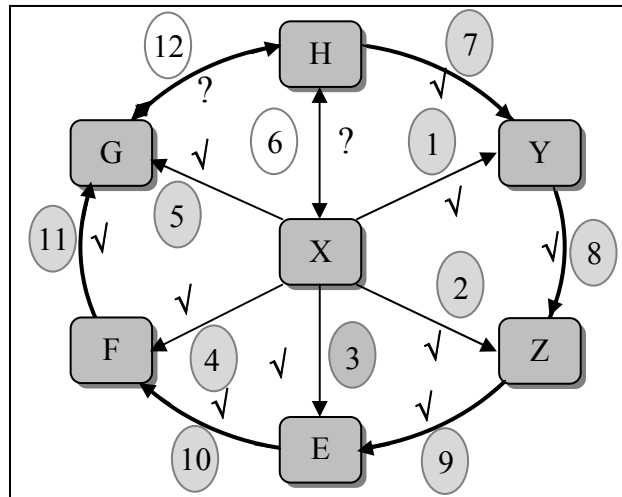


Fig. 7 SD<sub>2</sub>

In the last stage of the study of this unit, the student studies the two remaining relationships, 6 and 12, based on the previously studied relationships, then the student adds them to SD<sub>2</sub> to obtain SD<sub>f</sub> (Fig. 8) which is the end of the systemic teaching and learning of this unit.

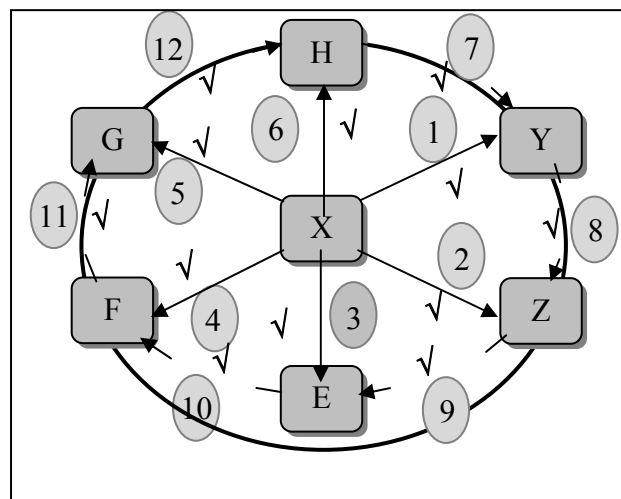


Fig. 8. SD<sub>f</sub>

All the relationships between concepts 1 – 12 have become known in SD<sub>f</sub> (Fig. 8); and SD<sub>f</sub> is the terminal systemic diagram for teaching this unit.



From the scenario of teaching this unit, we extract the following general observations. We started teaching the unit using the systemic diagram  $SD_0$ , that has been determined by the teacher as the starting point of the unit, and we ended with the systemic diagram  $SD_f$  that defined the terminal point of the unit; between the two systemics we pass through the diagrams  $SD_1$  and  $SD_2$ .

The systemic diagrams involved using the approach to study are similar except that the number of known relationships ( $\surd$ ) and the unknown ones (?). As we proceed in teaching the unit, the unknown relationships become diminished while the known ones increase until we reach the end where all the relationships become known as indicated in Fig. 2. The systemic diagrams are used in the related processes of teaching and learning, but not as summaries for memorization. It is the process of building (constructing) the overall diagram that helps both teacher and student; it helps the teacher to teach and the student to learn and the process can be utilized from the beginning to the end of teaching material in the unit. In a sense, the terminal systemic diagram is a summary of the unit contents, but the important aspect of SATL techniques is the process.

In our experience, students become aware of the characteristic pathways of teaching the unit from its beginning to its end, which can raise their motivation and can help them to interconnect the knowledge they study at any of the teaching stages with the past and the next concepts in the unit. Repeating this process appears to help students to build a richer cognitive structure of the subject of study.

At the end of their study, students could be asked to build numerous systemic diagrams that show the relationships between 3, 4, 5, or 6 concepts. The results can indicate the extent of student achievement of the unit objectives through the final systemic assessment (*vide infra*).

### **SATL—Aromatic Chemistry: a specific example**

It is often difficult to employ a detailed, but generalized approach of a new teaching/learning paradigm. We present here a specific chemically-related example of the application of SATL methods. We use, namely, aromatic chemistry—the chemistry of benzene—to illustrate how a subject can be organized systemically, to help students to fit new concepts into their own cognitive structure.

The details of the transformation of the linear approach usually used to teach students about aromatic chemistry such as the separate chemical relationships among benzene and other related compounds are shown in Fig. 9, which is a representation of a linear approach to teaching. The corresponding systemic diagram  $SD_0$  appears in Fig. 10.

The chemical relationships between benzene and benzene derivatives (toluene, bromobenzene, phenol, nitrobenzene, benzenesulphonic acid, etc.) are summarized in the diagram shown in Fig. 9, which looks like a series of linear relationships are connected by benzene. Fig. 9 looks a bit like it may have started to be a concept map, but the person generating it gave up. In effect, Fig. 9 is a summary of the individual reactions that makeup the chemistry of benzene, but it has very little use as a teaching device.

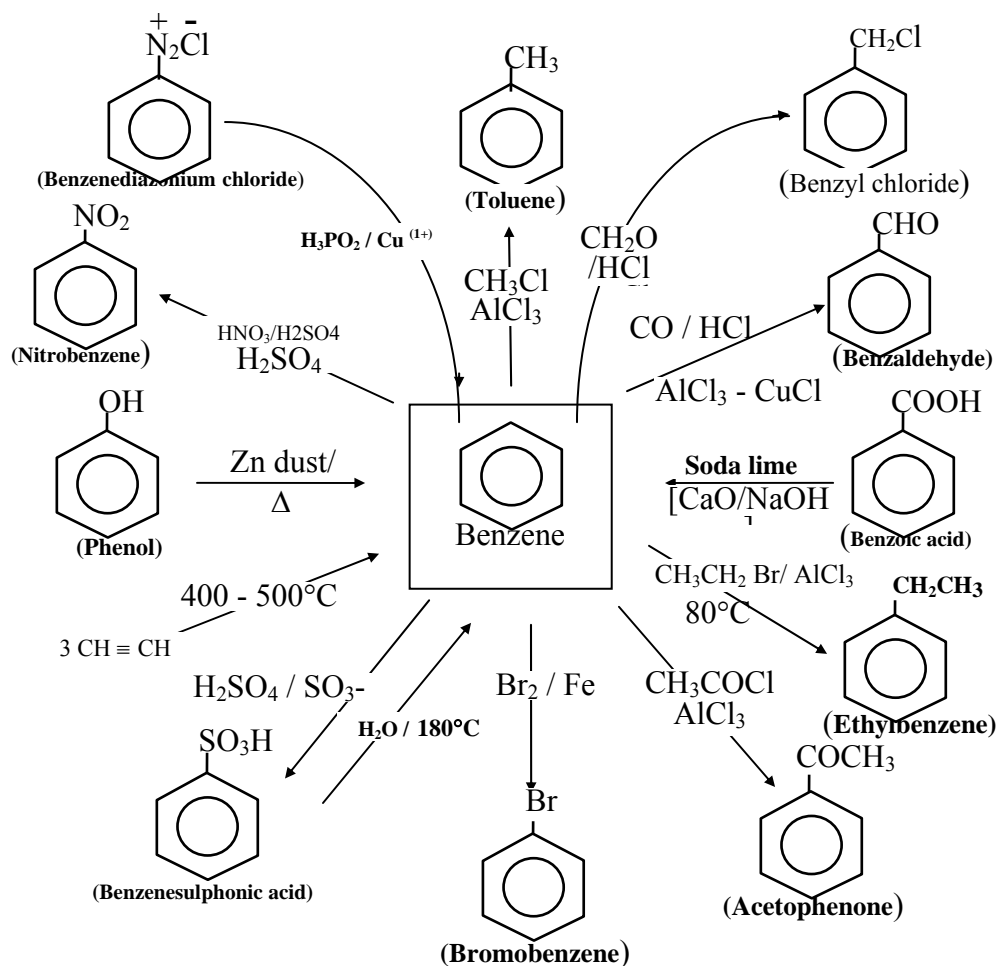


Fig. 9. Linear chemical relationships between benzene and related compounds.

We can illustrate the linear chemical relationships that appear in Fig. 9 in the following systemic diagram, shown as Fig. 10 (SD<sub>0</sub>).

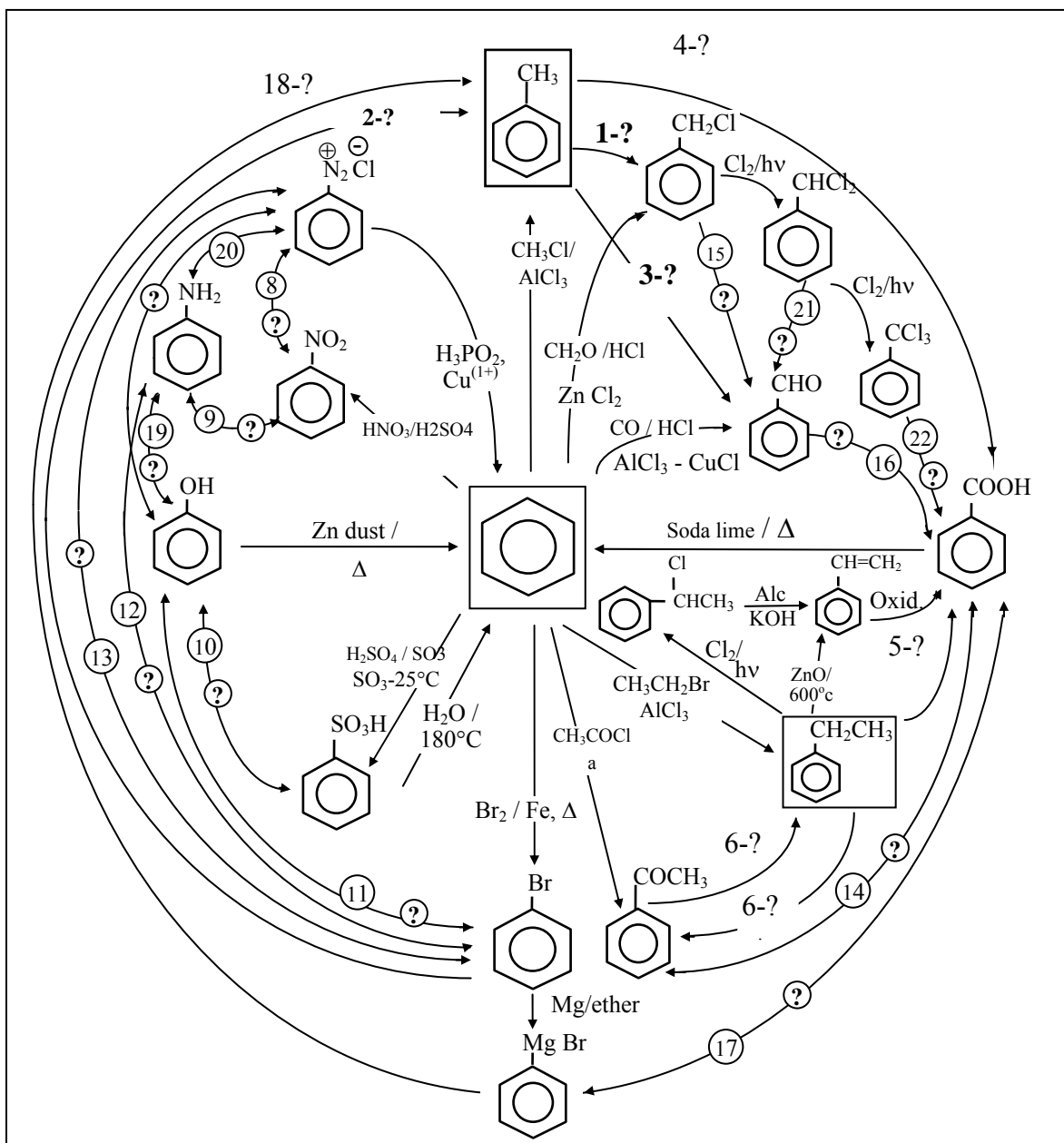


Fig. 10.  $SD_0$  represents some of the major reactions of benzene and benzene derivatives.

In the systemic diagram  $SD_0$  (Fig. 10.) some of the chemical relationships are defined (known to the student) whereas others are undefined (to be learned by the student). The known relationships have to be carefully defined by the teacher. They may be based on prior knowledge,

or they will be discussed initially in some detail. The undefined relationships are developed systematically.

After using the diagram shown in Fig. 10 as the basis for the study of the synthesis and reactions of alkyl benzene, we can modify this systemic diagram ( $SD_0$  in Fig. 10) to accommodate other chemistries of benzene and alkyl benzenes as shown in  $SD_1$ , Fig. 11.

We can modify the  $SD_0$  to  $SD_1$  by adding the defined chemical relations of 1-6 and 18. But we still have undefined chemical relationships of 7-17 besides the other four unknown chemical relationships, 19 - 22.

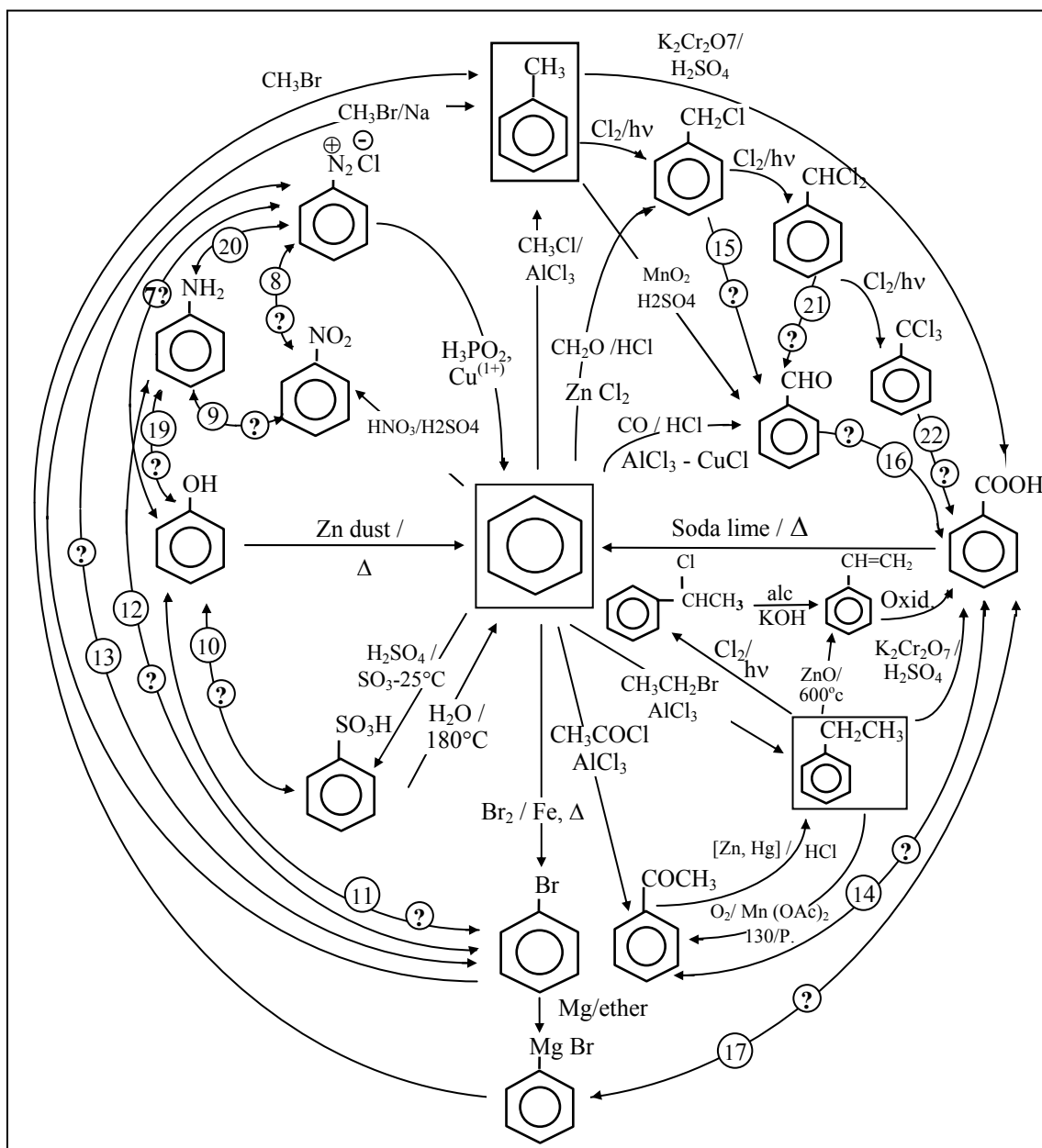


Fig. 11. SD<sub>1</sub> represents some of the major chemistries of benzene and alkyl benzene.

After studying synthesis and chemical reactions of halogen derivatives of benzene, we can modify this systemic diagram, SD<sub>1</sub> (Fig. 11), to accommodate other chemistries of halo benzene as shown in SD<sub>2</sub>, Fig. 12.

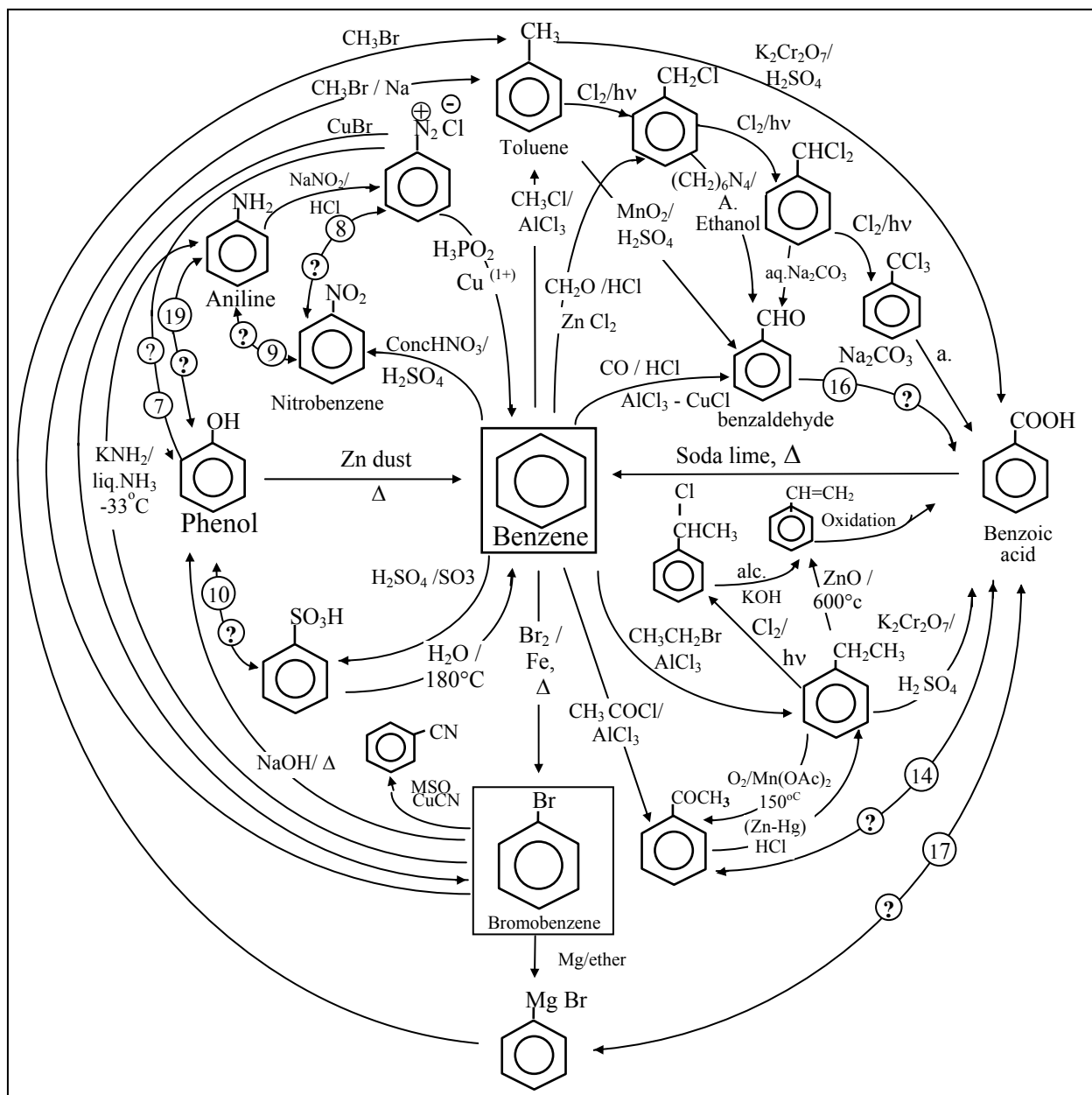


Fig. 12. SD<sub>2</sub> represents some of the major chemistries of benzene, alkyl benzene, and halo benzene.

In SD<sub>2</sub>, Fig. 12, we still have undefined chemical relationships between 7-10 besides the four other relationships, 14, 16, 17, and 19. These will be clarified after studying the remainder of the course.

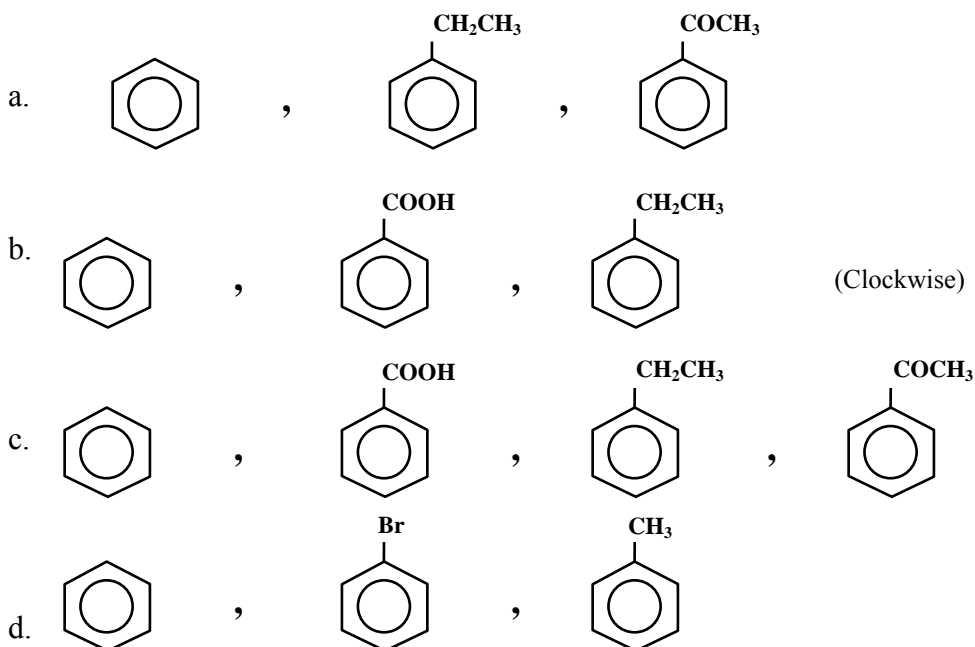
A course on aromatic chemistry using the SATL technique was organized and taught to 2<sup>nd</sup> year students at Menoufia University [4]. The one-semester course (16 lectures, 32 hours) was taught successfully to 28 students during the academic year 2000/2001.

## SYSTEMIC ASSESSMENT ON [ SD<sub>1</sub> AND SD<sub>2</sub>] IN THE AROMATIC CHEMISTRY

### UNIT

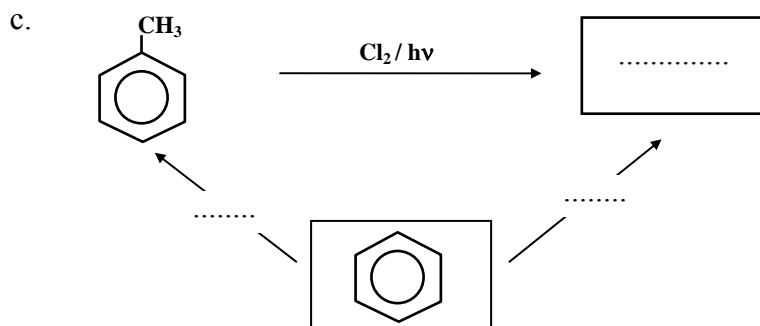
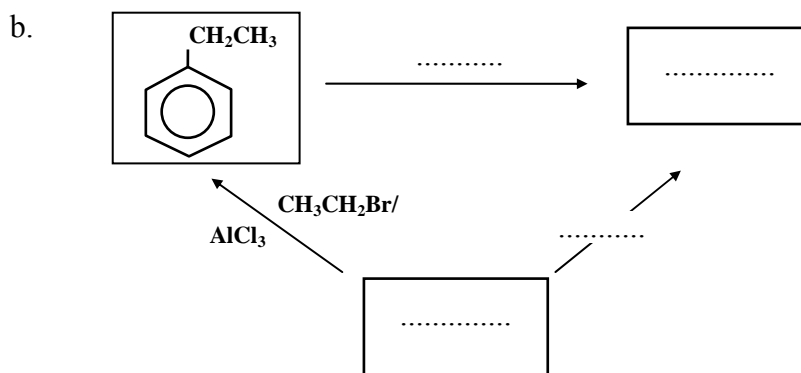
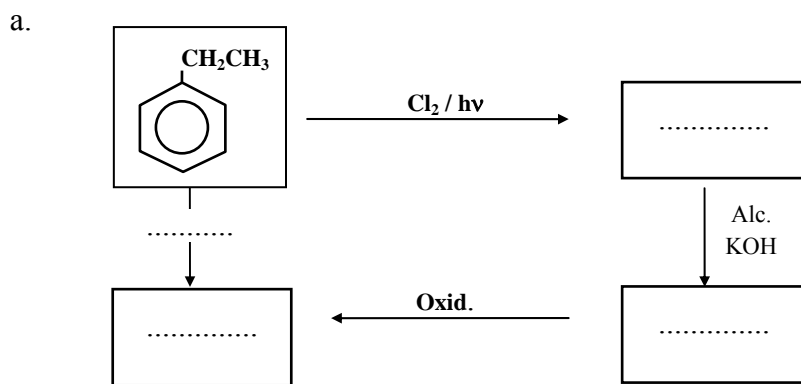
Assessment of student learning using SATL methods can be made as in the case of any teaching/learning paradigm. The following illustrate the kinds of questions that have been used successfully for assessment purposes.

I) Draw systemic diagrams illustrating chemical relationships between the compounds of each of the following sets.

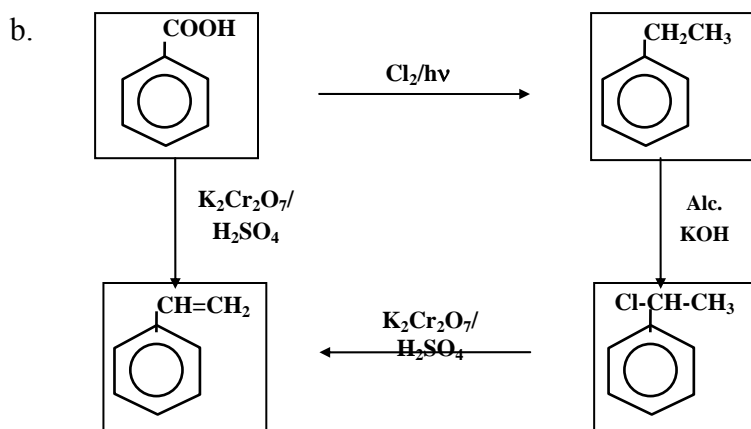
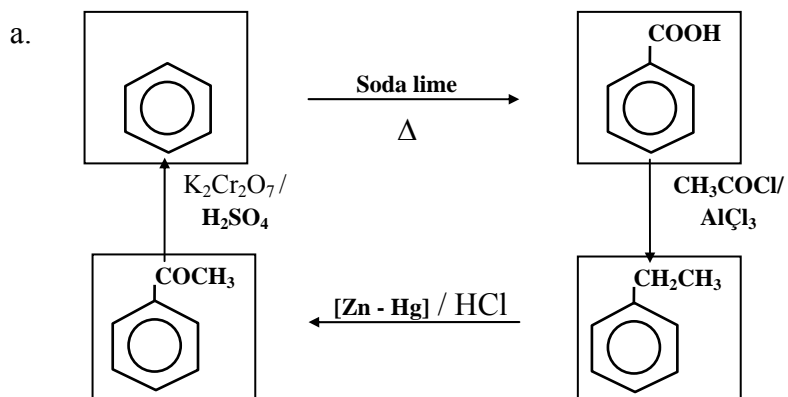




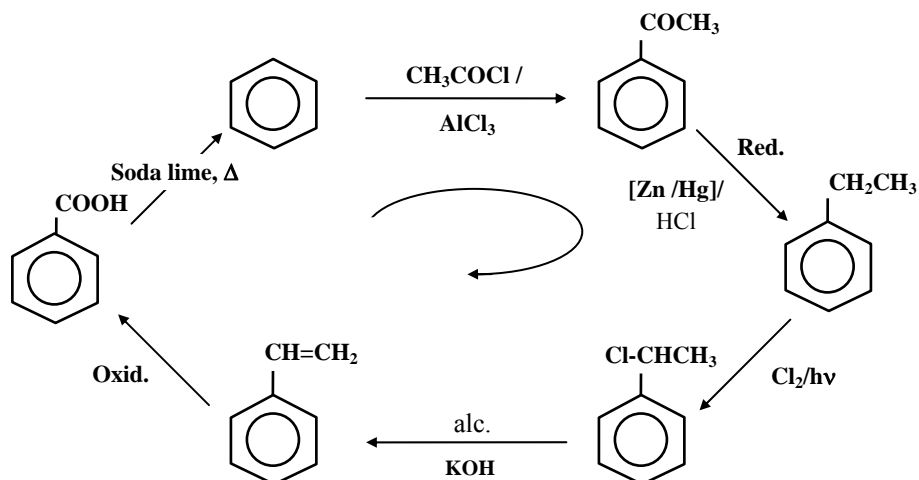
II) Complete the following systemic diagrams.



III) Correct the following systemic diagrams.



IV) Convert the following SD into the equivalent chemical equations.



## REFERENCES

1. Fahmy, A. F. M.; Lagowski, J. J. (2011). The Systemic Approach to Teaching and Learning; A 10-year Review. AJCF, 1(1), pp.
2. (a) Ausubel, D. P.; Novak, J. D.; and Hanesian, H. *Educational psychology: A cognitive view*. New York: Reinhart and Winston, 1968. (b) D. P. Ausubel, J. D. Novak, and H. Hanesian, *Educational psychology: A cognitive view*. New York: Holt, Rinehart, and Winston, 1978.
3. (a) Novak, J. D. *Learning, Creating and Using Knowledge*. Wahwah, NJ: Lawrence Erlbaum, Associate, and references therein, 1998. (b) Novak, J. D. and Gowin, D. B., *Learning how to learn*. Cambridge: Cambridge University Press, 1984.
4. Fahmy, A. F. M.; Hashem, A. I.; Kandil, N. "Systemic Approach in Teaching and Learning Aromatic Chemistry" Science Education Center, Cairo, Egypt 2001.