AFRICAN JOURNAL OF CHEMICAL EDUCATION

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Research and practice show us that multiple approaches have been used in teaching Chemistry and in assessing the corresponding students’ learning in general and specific aspects of Chemistry in particular. Whereas some authorities conducted controlled experimental research in order to identify which approach works best under a given context, others rely on personal experiences in teaching chemistry and tell us what works when and why.

This issue of AJCE brings to you cases from different parts of the world that highlight the above stated practices. The articles included here discuss i) problem solving approach as an experimental study on teachers’ behaviors on the one hand and as students use of a triangle method on the other, ii) diagnosis of students’ misconceptions through two-tier versus three-tier tests and through the use of concept cartoons versus systemic assessment, and iii) pedagogical implications of basic chemistry concepts and approaches.
RELATIONSHIP OF SOME VARIABLES IN PREDICTING PRE-SERVICE TEACHERS’ PROBLEM SOLVING PERFORMANCE IN CHEMISTRY

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ABSTRACT
The study examines the extent to which the relationship between pre-service Nigerian Certificate in Education (NCE) teachers’ academic level, college specialization and gender could predict their problem solving performance in chemistry. The sample for the study involved two hundred and four, 200 and 300 level, chemistry major and non-major pre-service teachers drawn from eight colleges of education of Plateau and Six states of Northeast Nigeria. Three instruments were developed and used for data collection. Namely, chemistry problem-solving test (CPST); chemistry achievement test (CAT) and mathematics skill test (MST). Data were analysed using one-way ANOVA, t-test and multiple regression. The results showed that, based on academic level and college specialization, there was a significant difference between the mean problem-solving performances of the pre-service teachers at 0.05 α-level. However, there was no significant difference between the mean performance of male and female pre-service teachers. Academic level, college specialization, and gender taken together significantly predict pre-service teacher’s problem solving performance. Among these three independent variables, academic level contributed most in the prediction. [AJCE, 2(2), February 2012]
INTRODUCTION

One of the important goals of chemistry education is the acquisition of problem-solving skills. Possession of superb problem-solving skills generates a sound base for good performance in different aspects of chemistry (1). Problem solving has been acknowledged as a paradigm of complex cognition that is part of our everyday experience (2). Danjuma (3) defines problem solving as a process whereby an individual or a group uses previously acquired knowledge and skill to meet (solve) the demand of a particular situation (problem).

Most researchers working on problem solving (4–8) agree that a problem occurs only when someone is confronted with a challenge for which an immediate answer is not available. Klein (6, p. 328) defines a problem as a situation in which a person is motivated to reaching a goal but attainment of the goal is blocked by some obstacle or obstacles. From this definition and those of other researchers, there appeared to be some commonality in ideas about the concept of a “Problem”. First of all, for a question, a goal or an objective to be a problem it must be a challenge to the solver. Secondly, the solver must be willing to accept the challenge. Thirdly, the solver must have no readily accessible methods for obtaining the solution to the question, goal or objective. These three conditions have to be satisfied for a situation to be regarded as a problem. Many studies on problem solving in chemistry deal with a wide range of issues. Some (9–16) focused on the nature of problems and problem-solving processes whereas others (17–20) on instructional methods and strategies. Still other researchers have shown how certain variables relate to students’ problem-solving performance. Examples of such variables include learner’s cognitive style (21–22) and gender (22; 14). However, the
results of some of these studies seem to suggest that students’ success in problem solving depends on teachers’ knowledge and disposition to problem solving. Bajah and Bello (18) report that teachers neglect the implementation of problem-solving instructional strategies during chemistry teaching. In an earlier work on recurrent difficulties in problem-solving, (10) had explained that many of the students’ difficulties in chemistry problem-solving could be traced to the problem-solving behavior of the teacher. They add that teachers pay too little explicit attention to several phases of problem-solving processes that are essential to students.

It is against this background that the present study focused on investigating the chemical problem-solving behaviors of pre-service teachers. Relatively few papers have appeared in the chemistry education literature on problem-solving behaviors of pre-service chemistry teachers especially in Nigeria. Some of these few studies include the works of (23--24) on pre-service teachers’ misconceptions in chemical equilibrium and chemical kinetics respectively. Another involves pre-service teachers’ performance in stoichiometry (25). A more recent one is the results of part of a research (26) on problem-solving behaviors of pre-service teachers (that were considered in this study). He (26) found that, irrespective of their academic level and college specialization, the pre-service teachers used appropriate methods to solve chemistry problems. Method use was more pronounced among the chemistry majors. However, only few of them were successful in getting the correct answer.

**PURPOSE OF THE STUDY**

The main purpose of the study was to determine the relationship between three independent variables: pre-service teachers’ academic level, college specialization and
gender in predicting their problem-solving performance in chemistry. The specific objectives are to:

a. examine pre service teachers’ problem-solving performance

b. determine the extent to which pre-service teachers’ academic level, discipline, and gender when taken together could predict their problem-solving performance

c. examine the relative contribution of each of the three independent variables of academic level, discipline and gender to the prediction of their problem-solving performance

METHODOLOGY

Design of the Study

The research was a descriptive study that employed ANOVA, Post Hoc comparison using Tukey’s Honestly Significant Difference test (HSD) and t-test to examine the problem-solving performance of the pre-service teachers. A correlation methodology, specifically, multiple regression was used to determine the extent to which the three independent variables combined together could predict their problem-solving performance and also to find out the contribution of each variable to the prediction. All the statistical tests were done at 0.05α-level.

Participants

The population for the study comprised eight hundred and seventy nine, 200 and 300 levels pre-service Nigeria Certificate in Education teachers majoring in chemistry and those that have taken chemistry as a minor/non-major teaching subject from eight colleges of education located in Plateau and six states of the Northeast geopolitical zone of Nigeria. The sample for the study comprised two hundred and four pre-service
teachers drawn from the population. Specifically, fifty seven 200 level chemistry majors, sixty six 300 level chemistry majors, forty 200 level non-majors and forty one 300 level non-majors.

The reasons for choosing these groups of pre service teachers as explained in (26) was that, at their present academic levels, they must have been offered enough chemistry courses that have equipped them with some basic knowledge and skill needed for solving the selected quantitative problems. Secondly, experience shows that after completing their studies, these categories of pre-service teachers are being employed (in place to supplement graduate teachers) to teach chemistry at the secondary schools in Nigeria because the number of chemistry teachers is grossly inadequate especially in the Northern part of the country. Thirdly, prior to the administration of the CPST, their performance on a chemistry achievement test (CAT) and a mathematics skill test (MST) has indicated that they have possessed an appreciable knowledge of chemistry and mathematical skills required for solving the CPST items.

Stratified random sampling technique was employed to select the sample. Four strata were formed based on their academic level and college specialization. A random sample of 10 pre-service teachers from each stratum from each of the eight colleges of education was drawn [except for one college where the population of 300 level chemistry majors was less than 10; in this case, the whole population (N = 7) was sampled].

Data Collection Instruments

For the purpose of this study, three instruments, namely, chemistry problem-solving test, chemistry achievement test, and mathematics skill test, were developed by the researcher. The chemistry problem-solving test (CPST) was a four-item free response
test developed by the researcher (see Appendix A). Each item in the test represents one of the four topics in chemistry (i.e. composition of chemical substances, stoichiometry, gas laws, and electrolysis) found in the foundation chemistry courses of most of the colleges of education and at first-year undergraduate level of Nigerian Universities. The total score in the test was considered as a measure of the sample’s problem-solving performance. The CPST was designed based on the measurement criteria for Problem-Solving Tests reported in the literature (27). In addition, a CPST scoring guide and a CPST model answer were developed and used for scoring the responses of pre-service teachers. As a problem-solving free-response test, the CPST has no time limit because they were required to record all the details of their thinking as they solved the problems.

The chemistry achievement test (CAT) was a 40-item multiple choice test with four alternative responses. The items were those selected out of the pool of the 60 that have been trial-tested. The content of the test covered the areas in chemistry judged by experts in chemistry education at the Abubakar Tafawa Balewa University, Bauchi, Nigeria as having provided the background knowledge for solving the problems contained in the CPST. The total score from the test was considered as a measure of the respondents’ background knowledge in chemistry. The duration for the CAT was 60 minute.

The mathematics skill test (MST) was a 20-item multiple choice test with four alternative responses. The items were those selected out of the pool of 40 items that have been trial-tested and considered to be adequate for measuring mathematics skills. The items were drawn from mathematics topics that have applications in chemistry as judged by experts in chemistry and mathematics education. The total score in the test was
considered as a measure of its respondents’ mathematical skill necessary for solving numerical problems in chemistry. The duration for the test was 45 minutes.

Each of the three tests was pilot tested to obtain data for determining it’s reliability. The CPST was subjected to an appropriate method of determining reliability of an essay test. That is, the inter-scorer method. The method involves correlating two sets of scores of the candidates obtained from independent scorers (28). Two experts, in chemistry education participated in this exercise. Each was given copies of participants test scripts obtained from two pilot trials. They scored the scripts using the CPST scoring guide and CPST model answers. The resulting two sets of scores obtained were correlated using Pearson’s product-moment correlation formula and a correlation (reliability) coefficient of 0.62 was obtained. While the split-half method was used to establish the reliability values for the CAT and MST which were 0.71 and 0.77 respectively.

RESULTS AND DISCUSSION

Pre service Teachers’ Problem-Solving Performance

Table1 presents the analysis of variance (ANOVA), testing whether there was significant difference among the problem-solving performance among 200 level majors and non-majors and 300 level majors and non-majors. From the table, the F-value of 3.62 was obtained which was found to be significant at 0.05 α-level. This implies that differences existed among the means problem-solving performance of the pre-service teachers, that is, they performed differently in the chemistry problem-solving test. The effect size f of the F-value from the ANOVA results was also determined using the formula developed by (29). Effect size gives an indication of the strength of the influence
of the independent variables on the dependent variable which, in this case, were academic level and college specialization.

Developments on the use and reporting of statistical techniques (30--32) have emphasized that when a mean difference was found to be significant in a statistical analysis, an accompanying effect size statistic and/or a statistic demonstrating the amount of variance accounted for by the observed difference should be included to support the main statistical results. An effect size of 0.23 was determined for the F-value from the ANOVA test presented in Table 1. This value was considered to be small based on Cohen’s scale, implying that, although the independent variables had significant influence on the dependent variable (problem-solving performance). However, the value of the effect size was too low to inform a decision on pedagogical practice.

**TABLE 1**: The ANOVA Results of the Problem-Solving Performance of the Pre-service Teachers

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1471</td>
<td>3</td>
<td>490</td>
<td>3.62</td>
<td>0.014</td>
</tr>
<tr>
<td>Within Groups</td>
<td>27110</td>
<td>200</td>
<td>136</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28581</td>
<td>203</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Table 1 at the 0.05 $\alpha$ - level, the $F_{calculated} = 3.62 > F_{critical} = 2.65$.

The effect size for the F-ratio, $f$ was determined using the formula developed by (14),

$$f = \sqrt{\frac{\eta^2}{1 - \eta^2}}$$

where

$$\eta^2 = \frac{SS_{between}}{SS_{total}}$$

SS between and SS total are obtained from the ANOVA Table

$$\eta^2 = \frac{1471}{28581} = 0.051$$

Therefore

$$1 - \eta^2 = 1 - 0.051 = 0.949$$

$$f = \sqrt{\frac{0.051}{0.949}} = 0.23$$
TABLE 2: The Means of the Pre-service Teachers in the CPST

<table>
<thead>
<tr>
<th>Statistic</th>
<th>NCE II Chemistry Majors ($\bar{X}_1$)</th>
<th>NCE II Chemistry Majors ($\bar{X}_2$)</th>
<th>NCE II Non-Majors ($\bar{X}_3$)</th>
<th>NCE II Non-Majors ($\bar{X}_4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ($\bar{X}$)</td>
<td>31.46</td>
<td>33.41</td>
<td>25.98</td>
<td>32.34</td>
</tr>
</tbody>
</table>

TABLE 3: Pair wise Comparisons Between All Means Using the Tukey’s HSD Test

<table>
<thead>
<tr>
<th>Comparisons</th>
<th>Difference</th>
<th>HDS Value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{X}_1 - \bar{X}_2$</td>
<td>1.95</td>
<td>6.06</td>
<td>Not Significant</td>
</tr>
<tr>
<td>$\bar{X}_1 - \bar{X}_3$</td>
<td>5.48</td>
<td>6.06</td>
<td>Not Significant</td>
</tr>
<tr>
<td>$\bar{X}_1 - \bar{X}_4$</td>
<td>0.88</td>
<td>6.06</td>
<td>Not Significant</td>
</tr>
<tr>
<td>$\bar{X}_2 - \bar{X}_3$</td>
<td>7.43</td>
<td>6.06</td>
<td>Significant</td>
</tr>
<tr>
<td>$\bar{X}_2 - \bar{X}_4$</td>
<td>1.07</td>
<td>6.06</td>
<td>Not Significant</td>
</tr>
<tr>
<td>$\bar{X}_3 - \bar{X}_4$</td>
<td>6.36</td>
<td>6.06</td>
<td>Significant</td>
</tr>
</tbody>
</table>

HSD 0.05/3 = 6.06

As mentioned earlier, a pair wise Post Hoc comparison of the mean problem-solving performance was also made using Tukey’s Honestly Significant Difference Test (HSD) and presented in Table 3. The purpose of this comparison was to ascertain where the significant difference that existed among the means from the ANOVA. The results obtained revealed that, there existed significant differences between the means of 300 level majors and 200 level non-majors, and that between 300 level non-majors and 200 level non-majors respectively. The result still indicated that, among the independent variables considered, academic level of the pre-service teachers seems to have greater influence on their problem-solving performance. The influence of college specialization was not much. The result presented in Table 4 indicates that, there was no significant difference between the mean problem-solving performance of male and female pre-service teachers. This result was contrary to the finding of (22) who reported a
differential performance in chemistry problem-solving tasks, with the girls significantly performing better than the boys. Ajagun attributed the differential performance to the fact that a larger number of the female subjects in her study were drawn from single-sex schools.

TABLE 4: Summary of Analysis for the t-test for Gender Difference in Problem-Solving Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>SE</th>
<th>Df</th>
<th>t_cal</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>153</td>
<td>31.80</td>
<td>12.10</td>
<td>0.98</td>
<td>203</td>
<td>1.52</td>
<td>0.13</td>
</tr>
<tr>
<td>Female</td>
<td>51</td>
<td>29.10</td>
<td>10.60</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( t_{\text{critical}} = 1.96 \)

**Using the Independent Variables to Predict Problem-Solving Performance**

The results presented in Table 5 showed the extent to which the independent variables when combined together could predict pre-service teachers’ problem-solving performance in chemistry. The table showed the coefficient of multiple-regression (R) of 0.22 and \( R^2 \) of 0.048 were obtained, all low indicating a weak relationship. However, the ANOVA for the multiple-regression produced an F value of 3.33 that was significant at 0.05 \( \alpha \) - level indicating that the effectiveness of the joint contributions of the three independent variables mentioned in predicting pre-service teachers’ problem-solving performance could not have occurred by chance. The magnitude of the relationship under consideration is reflected in the values of the coefficient of multiple-regression (R) where a value of 0.22, and a multiple regression square (\( R^2 \)) with 0.048 (4.8%) and multiple regression square adjusted of 0.033 (3.3%) obtained. These results are indications that pre-service teachers’ academic level, specialization and gender taken together accounted for only 4.8% of the total variance in their problem-solving performance. That is, we
have got 4.8% of the variance to make prediction about their problem-solving performance and 3.3% of the variance to make correct prediction.

To ascertain the contribution of each of the independent variables in making the prediction, the regression weights ($\beta$) of the independent variables were computed and tested by converting them to t-values. These results were presented in Table 6.

**TABLE 5: The Results of Multiple Regression for Pre-service Teachers’ Academic Level, Discipline, and Gender against their Problem-Solving Performance.**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{crit}$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1343.9</td>
<td>3</td>
<td>448.0</td>
<td>3.33</td>
<td>2.65</td>
<td>0.05</td>
</tr>
<tr>
<td>Residual</td>
<td>26916.5</td>
<td>200</td>
<td>134.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28260.4</td>
<td>203</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Analysis of Variance for the Multiple Regression**

The results from Table 6 showed the contribution made by each of the three independent variables to the prediction of the problem-solving performance. The extent of contribution includes 3.468, 2.987, and 2.767 for academic level, discipline and gender respectively. These are the regression weights ($\beta$) for these independent variables. Also

$$t_{critical} = 1.96 \text{ at } 0.05 \alpha\text{-level}$$
from the table, the t-values associated with the regression weights indicated that only academic level contributed significantly to the predictive value of the pre-service teachers’ problem-solving performance. It implies that it was the only independent variable that contributed most to the prediction. The result seems to support those of Table 3 whereby, only pair wise comparison of means involving the academic levels were found to be significant in post Hoc comparisons. Those involving specialization were not.

The reason for the influence and contribution of academic level in predicting problem-solving performance may not be far from the fact that the pre-service teachers at level 300 must have had more experience with the contents of the chemistry courses than those at level 200, making them to perform better than on problem-solving tasks. Psychologists such as (5) and (6) and also researchers on problem-solving in science such as (33—35) have shown that experience was a very important factor for success in solving problems.

REFERENCES

APPENDIX ‘A
CHEMISTRY PROBLEM SOLVING TEST (CPST)

INSTRUCTION
Attempt all questions. You are expected to show clearly all the steps you have taken to arrive at your answer, including all rough works. You should also show how you have confirmed that your answer to each of the question is the correct answer. Direct all enquiries to your invigilator. Do not take away this question paper.

Q1. A gas at a pressure of 5.00 atm was heated from 0°C to 546°C and simultaneously compressed to one third of its original volume. What will be the final pressure in atm?
Q2. When aqueous copper (II) tetraoxosulpha te (VI) was electrolyzed between copper electrodes, masses in grams of the electrodes before experiment were the anode 9.20g and the cathode 7.75g. After the experiment, it was found that the mass in grams of copper anode was 6.00g. Calculate the mass in grams of copper cathode at the end of the experiment.
Q3. Given the equation below, what mass of ammonia would be produced from 1.0 mole of H₂ and excess nitrogen?

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \]

Q4. A strip of pure copper having a mass of 3.178g was strongly heated in a stream of oxygen until it was converted to the black oxide. The resultant black oxide has a mass of 3.978g. Calculate the percentage composition of the black oxide?
DIAGNOSING THE DIAGNOSTICS: 
MISCONCEPTIONS OF TWELFTH GRADE STUDENTS ON SELECTED CHEMISTRY CONCEPTS IN TWO PREPARATORY SCHOOLS IN EASTERN ETHIOPIA

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ABSTRACT

This article aimed at diagnosing suspected students’ misconceptions towards the selected five chemistry concepts (valence, oxidation number, coordination number, number of bonds and formal charge) by developing appropriate diagnostic instrument. Within this theme, it was also attempted to test the accuracy and precision of the common diagnostic tests in measuring students’ misconceptions and performance in terms of different test standards and standard indicators. To attain these goals, respective data were gathered through open-ended test and three-tier chemistry misconception test. The earlier was administered to identify major areas of students’ misconceptions, while the later was administered twice as a pilot and revised form. Using the result of the pilot test some items were rewritten accordingly. The result of the study showed that conceptual knowledge gained by these students was only superficial, accompanied by a range of misconceptions largely shared by about 28% of the sampled students. Finally, the findings of this study show that open-ended multiple choice items and two-tier tests are less valid, reliable and discriminatory than that of three-tier chemistry misconceptions test. [AJCE, 2(2), February 2012]
INTRODUCTION

In the area of chemical research, a significant number of studies involving diagnosis of suspected students’ misconceptions have been conducted. However, as can be seen from Temechegn (1), most of these studies targeted towards more advanced chemistry concepts. Contrary to this, basic chemical concepts which serve as prerequisite for understanding more complex and advanced concepts remain almost untouched. In addition, a number of debates have been rising regarding the reported or diagnosed set of respective misconceptions. The reasons behind such debates were found to be mostly attributed to the type of the diagnostic methods employed in each study. Most of these studies employed the easier diagnostic instruments like multiple choice items test and short answer test, which are blamed for being less accurate and precise in discriminating misconceptions from misunderstanding.

This study was aimed to diagnose students’ alternative conceptions of five selected chemistry concepts using open-ended and multi-tier misconception tests. Examining the potential of each type of the test in terms of different standard and standard indicators was also a part of the objectives of the study. A three-tier misconception test was preferred as a reference due to the fact that the rest, one and two-tier tests, were recommended to be less efficient in discriminating students’ misconceptions from misunderstanding (2).

The selected concepts are valence, oxidation number, formal charge, number of bonds and coordination number. They were given more emphases because of the following reasons. First, these concepts are highly interrelated, and are usually found to be introduced as similar concepts in early high school (3). Second, the causes of set of
diagnosed students’ misconceptions in higher chemical concepts like geometry, stability, structure and reactivity were suspected to be due to misleading application of such easy and basic concepts (1). Third, the magnitudes of these concepts for a given element are equal in most compounds containing the element, though it is simply a coincidence. It is only in neutral compounds and molecules consisting of element-element hetronuclear single bonds that the magnitudes of valence, oxidation number, coordination number and number of bonds are equal. For other cases the equivalence of magnitudes of all or some of these concepts breaks based on different circumstances. These circumstances are briefly discussed in Table 1.

Table 1: Circumstances where equivalence among oxidation number, valence, coordination number and number of bonding break (4).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Factors that cause the break down</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation number</td>
<td>i. Homonuclear element-element bonds are present</td>
<td>i. Me4C:C is tetravalent but has an oxidation number of zero</td>
</tr>
<tr>
<td></td>
<td>ii. Two ligands attached to the atom of interest have opposite charges (e.g., Cl- and H+)</td>
<td>ii. CH2Cl2: C is tetravalent but has an oxidation number of zero</td>
</tr>
<tr>
<td></td>
<td>iii. The molecule is charged and the ligand is dissociated as a cation (e.g., H+)</td>
<td>iii. [NH4]-: N is pentavalent but has an oxidation number of -3.</td>
</tr>
<tr>
<td>No. of bonds</td>
<td>The atom in question bears a formal charge (valence = no. of bonds + formal charge)</td>
<td>[BH4]-: B is tetravalent but has four bonds.</td>
</tr>
<tr>
<td>Coordination number</td>
<td>i. A multiple bond is present</td>
<td>i. H2 C=CH2: C is tetravalent but 3-coordinate HC=CH: C is tetravalent but 2-coordinate.</td>
</tr>
<tr>
<td></td>
<td>ii. A dative ligand is present</td>
<td>ii. H3NBH3: B is trivalent but 4-coordinate.</td>
</tr>
</tbody>
</table>

As a result, it was hypothesized that the set of suspected misconceptions were there, in students’ mind. It was also hypothesized that diagnostic instruments like open-ended, multiple choice items and two-tier test have less potential in identifying students’ misconceptions than the three-tier test.
METHODOLOGY

A cross-sectional survey research method was employed. The study comprised of two types of diagnostic tests which served as data gathering instruments. These are open-ended and three-tier misconception tests. The subjects of the study were 12th grade students from two preparatory schools in Eastern Ethiopia. These schools are Abboker Preparatory School from Hareri Region and Dire Dawa Comprehensive Secondary School from the second Federal City of Ethiopia, Dire Dawa. In the former school, there were 258 students in six sections out of which about 45% of them are females. In the later, there are a total of 486 students out of which about 38% of them are females.

Three test groups were formed; open-ended, pilot three-tier and the revised three-tier chemistry misconception test groups. The purpose of the earlier was to identify major areas of students’ misconceptions, while the pilot three-tier test was administered to examine standard of each item.

In the course of the study, related literatures were exhaustively consulted to find existing students’ misconceptions towards the selected concepts. Next, an open-ended test comprising of 8 main questions was accordingly prepared and administered for 48 students, 24 from each school. Then a three-tier misconception test consisting of 12 main items, each having three multiple choice items, was developed and administered for 56 students (28 from each school) as a pilot test. The result of this pilot test was analyzed and some items were accordingly re-written and the revised version was administered for 200* students.

* This number can fulfill the rule of thumb, proposed for minimum number of research participant in thesis level.
For simplifying the task of data analysis, seven variables were formulated in accordance with the desired outcomes. Based on the respective values of these variables, proportions of students’ scores and misconceptions were computed in terms of each tier of the test. Related parameters like validity (construct and content), reliability, item difficulty, and discrimination index were used to evaluate the standard of the items. The same set of parameters was used to compare the potential of each part of the tier as a separate diagnostic instrument.

RESULTS AND DISCUSSION

Open-ended Test

As already addressed, the purpose of this test was just to identify major areas of students’ misconceptions (5). The test comprise of 8 items. These items were organized in accordance with circumstances for which equivalence of magnitude of all, at least pairs, of the selected concepts break.

Item one offers students to discuss similarities among valence, oxidation number, number of bonds and coordination number. Item two focused on similarities and differences of oxidation number and formal charge of an element. Item three let students extend their perception to examine the possibility of generalizing the equivalence of valence, oxidation number, number of bonds and coordination number. Through this item, it was aimed to measure the confidence of the students in their respective answer to the first two items, and decide on such generalization.

Item four and item six are of similar circumstances. In these items, it was attempted to let students examine the impact of presence/absence of homonuclear and/or
hetronuclear element-element single/double bond(s) on the equivalence of magnitudes of the concepts. The difference is that item four considers only oxidation number and valence, while item six additionally entertain number of bonds and coordination number. On the other hand, item five ask students to notice oxidation number of an element under three circumstances; in free state, in its compound and in its radicals. Similarly, item eight ask students to examine the magnitudes of formal charge under above three circumstances. The remaining item, item seven, exposes students to correlate the magnitudes of oxidation number and formal charge of an element in its compounds and radicals.

Based on related misconceptions found in literature and students’ responses to items of this test, the results of the test were interpreted and grouped in to categories. Focusing only on those categories indicating misconceptions and correct responses, Table 2 was organized as follows. In this table, categories indicating misconception are those denoted by ‘M’, and those indicating correct answers were marked as ‘∗’. Only frequencies of categories showing correct answers and misconceptions were considered so that the remaining differences (out of 48) stand form wrong answers.

Table 2: Categories of students’ responses showing correct answers and misconceptions to wards the open-ended test

<table>
<thead>
<tr>
<th>Item</th>
<th>Categories</th>
<th>frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M Valence, oxidation number, number of bonds and coordination number are similar in that their magnitudes for a given element are equal for all compounds containing the element.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>* Valence, oxidation number, number of bonds and coordination number) are similar in that their respective magnitudes for a given element are equal only in neutral compounds consisting of hetronuclear elemenet-elemenet single bonds.</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>*Formal charge of a given element is constant in all compounds and radicals containing the element</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>*Formal charge and oxidation number are similar in that they are</td>
<td></td>
</tr>
</tbody>
</table>
concerned with charges assigned to a given element, though the conditions, in which the charges are assigned and their magnitudes are different.

3 *It is not always true that valence, oxidation number, number of bonds and coordination number of a particular element in its compounds have equal magnitudes. Because they have different values in complex compounds, complexes, radicals and hetronuclear molecules where multiple (double and triple) bond are present.

M It is possible to generalize that valence, oxidation number, number of bonds and coordination number of a particular element in its compounds have equal magnitudes.

4.1 M In every compounds of carbon, its valence and oxidation number are equal, but may or mayn’t be respectively 4 and -4.

*In every neutral compounds of carbon consisting only single bonds and in which homonuclear bond don’t exist, its valence and oxidation number are respectively 4 and -4.

4.2 M In every compounds of nitrogen, its valence and oxidation state are respectively 5 and -5.

*In every neutral compound of nitrogen in which there are no homonuclear and multiple bonds, its valence and oxidation state are equal, but the value is not common/fixed.

5 The oxidation number of an element in its neutral compounds (ex. N in NH₃) is equal to its oxidation number in radicals (ex. N in NH₄⁺)

M The oxidation number of an element in its neutral compounds (ex. N in NH₃) is not equal to its oxidation number in radicals (ex. N in NH₄⁺)

6 *In all compounds of carbons, as homonuclear carbon-carbon bond increase, oxidation number of carbon decreases. But coordination number, valence and number of bonds remain equally unchanged.

M In all compounds of carbons, presence of one or more homonuclear carbon-carbon bond doesn’t affect the magnitude of valence, oxidation number, coordination number and number of bonds remains unchanged.

7 M The formal charge of carbon (in its compounds) is equal to its respective oxidation state.

*The formal charge of carbon (in its compounds) could not always be equal to its respective oxidation state.

8 The values of formal charge of an element in its neutral compounds (ex, N in NH₃) and radicals (ex, N in NH₄⁺) are not equal (which are respectively 0 and +1).

The values of formal charge of an element in radicals (ex, N in NH₄⁺) and compounds containing the radicals (ex, N in NH₄Cl) are equal, which is +1.
In all cases, the proportion of students who were found to have misconceptions is higher than proportion of those students who have the desired conceptions. The average frequency of responses showing misconception was estimated as 43%, while frequency of those responses showing correct answers or desired conceptions is 30%. This revealed that most of students’ existing conception and understanding attributed to misconception.

The Pilot Three-tier Misconception Test

In this test, the average proportions of students’ misconceptions were respectively 48%, 36% and 26% for one, two and three-tier tests. On the other hand, the values of each parameters of test standard were summarized in Table 3 as follows

Table 3: Values of standard indicators of the pilot tree-tier misconception test in terms of each part of the tier.

<table>
<thead>
<tr>
<th></th>
<th>One-tier test</th>
<th>Two-tier test</th>
<th>Three-tier test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reliability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_{(Score)}$</td>
<td>0.61</td>
<td>0.65</td>
<td>0.78</td>
</tr>
<tr>
<td>$\alpha_{(misconception)}$</td>
<td>0.62</td>
<td>0.70</td>
<td>0.82</td>
</tr>
<tr>
<td><strong>Validity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct</td>
<td>Student</td>
<td>Score-2</td>
<td>Vs Confidence</td>
</tr>
<tr>
<td>Content</td>
<td>Mean Proportion of False Negative</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean Proportion of False Positive</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td><strong>Item analysis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D'$</td>
<td>0.28</td>
<td>0.29</td>
<td>0.36</td>
</tr>
<tr>
<td>$P^\xi$</td>
<td>0.38</td>
<td>0.32</td>
<td>0.33</td>
</tr>
</tbody>
</table>

* Reliability coefficient calculated based on students’ scores
+ Reliability coefficient calculated based on students’ misconceptions
‘ Average item discrimination index
$\xi$ Average item difficulty level

The average values of item difficulty level and discrimination index estimated from this pilot test fulfill the requirement of reported standard (6). However, some deviations were found in the case of individual value of each item. The item discrimination index of item 5 and 7, for example, are respectively 0.24 and 0.27. These values are less than that of the minimum acceptable value (0.30). As a result, these items were carefully reconsidered and revised. Such reconsiderations enabled the researcher to
omit some hint-giving alternatives of the respective items. In addition, the difficulty levels of item 1 and 10 were respectively found to be 0.18 and 0.21. In the same way these items were carefully reconsidered, some doubtful alternatives were found and rewritten.

**The Final Three-tier Misconception Test**

In this section, proportion of students’ scores and misconceptions were examined, figured out and discussed. The extent of students’ misconceptions in terms of each tier was evaluated in reference to findings of recent studies. In addition, students’ scores and their respective misconceptions of each tier were compared to that of the three-tier test results to evaluate the susceptibility of the first two tiers of the test towards guessing and overestimation of misconceptions.

<table>
<thead>
<tr>
<th>Item</th>
<th>Score-1 (%)</th>
<th>Score-2 (%)</th>
<th>Score-3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>47</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>34</td>
<td>31</td>
</tr>
<tr>
<td>5</td>
<td>48</td>
<td>42</td>
<td>37</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>38</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>37</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td>8</td>
<td>36</td>
<td>31</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>48</td>
<td>39</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>11</td>
<td>39</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>12</td>
<td>43</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>41</strong></td>
<td><strong>35</strong></td>
<td><strong>30</strong></td>
</tr>
</tbody>
</table>

This study revealed that the average percentage score of students declined with the nature of the test (Table 4). Students’ score in one-tier test (Score-1) is greater than that of two-tier test (Score-2). In turn, students’ score in two-tier test is greater than that of three-tier test (Score-3). In the same manner, the average percentage of students,
misconceptions declined as the tier of the test increased from one to three-tier (Table 5).

This evidences the shortcoming of one and two-tier tests in identifying misconceptions.

Table 5: Proportions of students’ misconception and percent by which the first two tiers overestimate students’ misconceptions

<table>
<thead>
<tr>
<th>Item</th>
<th>One-tier test</th>
<th>Two-tier test</th>
<th>Three-tier test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Misc-1 (%)</td>
<td>Misc-2 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of overestimation</td>
<td>% of overestimation</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>37</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>53</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>41</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>32</td>
<td>32</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>47</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>34</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>11</td>
<td>38</td>
<td>33</td>
<td>23</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>average</td>
<td>40</td>
<td>36</td>
<td>28</td>
</tr>
</tbody>
</table>
Considering the values in the last row of Table 5, it is possible to generalize that one-tier test overestimate students’ misconception by 12% while the two-tier test overestimate students’ misconception by 8%. This implies that diagnostic tests like multiple choice items and two-tier tests are less efficient in identifying the extent of students’ misconceptions. As a result such tests are not potential enough to discriminate misconception from lack of knowledge. On the other hand, values of the respective parameters for each part of the final three-tier misconception test were shortly presented in Table 6.

Table 6: Values of standard indicators of the revised three-tier misconception test in terms of each part of the tier.

<table>
<thead>
<tr>
<th>Reliability</th>
<th>One-tier test</th>
<th>Two-tier test</th>
<th>Three-tier test</th>
</tr>
</thead>
<tbody>
<tr>
<td>α (Score) †</td>
<td>0.61</td>
<td>0.65</td>
<td>0.78</td>
</tr>
<tr>
<td>α (misconception)†</td>
<td>0.66</td>
<td>0.76</td>
<td>0.87</td>
</tr>
<tr>
<td>Validity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct</td>
<td>Student Score-2 Vs Confidence Level</td>
<td>Mean Proportion of False Negative 6% Mean Proportion of False Positive 12%</td>
<td>0.45</td>
</tr>
<tr>
<td>Content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item analysis</td>
<td>D‘</td>
<td>0.28</td>
<td>0.32</td>
</tr>
<tr>
<td>P£</td>
<td>0.41</td>
<td>0.35</td>
<td>0.33</td>
</tr>
</tbody>
</table>

* Reliability coefficient calculated based on students' scores
+ Reliability coefficient calculated based on students' misconceptions
† Average item discrimination index
‡ Average item difficulty level
Table 6 illustrates that it is almost only in the case of a three-tier test that the values of test standard measuring parameters fulfill the minimum requirements of the respective acceptable values (6). The reliability coefficient, \( \alpha \), calculated based on students’ scores and misconceptions of the three-tier test are respectively 0.78 and 0.87. These are greater than the reported acceptable value, which is 0.70 (7). The first implies that about 78% of the variance of students’ score is due to the variance of the true students’ scores, while the later shows that about 87% of the diagnosed students’ misconceptions are due to the variance of the true students’ misconceptions (2).

Regarding item analysis, the average discrimination indices are 0.28 and 0.32 respectively for one and two-tier tests. But the average item discrimination index calculated based on the three-tier test was found to be 0.36. This implies that items of three-tier misconception test were more discriminatory (6). However, the average item difficulty level, which is 0.30, is less than that of the minimum accepted value (0.50), though diagnostic tests are not needed to fulfill this requirement (8). The correlation of students’ score (Score-2) and confidence level, which is 0.45 at a 0.01 significant level, is positively significant.

This can assure that high scorers are more confident in their answer than low scorers-an indication for an attainment of construct validity (9). The mean proportion of false negative, which was found to be 6%, falls in the domain of acceptable range (1% to 10%). And the mean proportion of false positive was found to be 12%. According to Rollnik and Mahooana (9), the last two parameters show that a content validity of the three-tier misconception test was successfully maintained.
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Early diagnostic aspects which focus on basic chemical concepts are almost remaining untouched. Moreover, most local diagnostic researches were found to stick to short answer and multiple choice items test, which have been blamed for being less efficient in discriminating misconceptions from misunderstanding (10-11). As a result, it was aimed to diagnose students’ misconceptions by using open-ended, one, two and three-tier tests.

The subjects of the study were twelfth grade students of the selected two schools. Systematic random sampling method was employed to select students for the three test groups. So, the data gathering instruments were open-ended and three-tier chemistry misconception tests. The gathered data were analyzed in terms of the already formulated seven variables. The respective values of standard indicators of each item were also calculated. From the result of the open-ended test, about 11 major areas of students’ misconceptions were identified. In addition, from the result of the three-tier chemistry misconception test, about 28% of the students have the suspected misconceptions.

On the other hand, the reliability coefficient of the test calculated based on students’ scores and misconceptions were 0.78 and 0.87 whereas the item difficulty level and average discrimination index were found to be respectively 0.30 and 0.36. Concerning the validity parameters, the mean proportion of false positive is 12%, while that of false negative is 6%. The correlation of students’ score (score-2) and their confidence level resulted 0.45 at a 0.01 significance level. In addition, the following new or unexpected misconceptions were also found.
Most students believe that the valence of an atom in its free state and compound form is the same. According to these students, the valence of magnesium, for example, is 2 in both neutral magnesium metal and its compounds consisting of Mg$^{2+}$.

Parallel to the above, students believe that oxidation number of an element in its free state and compounds is equal. In manganese, for example, its oxidation number in neutral manganese (Mn) and its compounds consisting of Mn$^{2+}$ are equally +2.

Students were also found to have misconception in terminology of these concepts. Because some of them reflected and used valence to mean oxidation number.

Noticing the formal charge of elements (like that of N in NH$_4^+$), students used to generalize that the formal charge of elements is always equal to the charge of respective polyatomic ions. This generalization went beyond the condition after the polyatomic ion reacted with others and form neutral compounds. For example, according to these students, the formal charges of nitrogen in ammonium ion (NH$_4^+$) and ammonium chloride (NH$_4$Cl) are the same and equal to charge of ammonium ion (+1).

Conclusions

The following conclusions were drawn based on the findings of the study.

- About 28% of the students’ were found to have the suspected sets of misconceptions.
- One and two-tier tests overestimate students’ misconception by about 12% and 6% respectively.
- Open-ended test, one and two-tier tests are less reliable, valid and discriminatory in diagnosing students’ misconceptions and performance.
- The proportion of students’ score decreased as the tier of the test increased. The difference between average students’ misconception for one-tier test and two tier tests is
6%. This can be attributed to the value of proportion of false negative. And that of the two-tier test and three-tier test is 8%, which can be attributed to lack of knowledge.

- Similarly, the difference between average proportion of students’ scores in one-tier test and two-tier test is 6%. This is exactly equal to the value of false positive. And that of the two-tier test and three-tier test is 5%, which can be attributed to lack of knowledge and inconsistent students’ answers.

Recommendations

Based up on the findings of this study, the following recommendations were formulated for chemistry teachers, researchers, educators and policy makers.

- Teachers should note the seriousness of misconceptions of such easy (but basic) chemical concepts, and are encouraged to develop and use TTCMT to diagnose misconception of their students.

- Rather than using multiple choice items, it is really advantageous to develop a multi-tier misconception test. Because, multiple choice item tests were found to overestimate the extent of students’ misconceptions.

- Researchers, policy makers and educators are highly advised to focus on developing TTMT, evaluate its effectiveness in different context for different subject and look for effective methods to bring about the desired conceptual change.

- Every stakeholder should be sure enough of not intermixing misconception with lack of knowledge. In fact, using TTCMT let anyone be free from such technical and pedagogical biases.
REFERENCES


ACKNOWLEDGEMENT

I am very glad to express my special and heart-felt thanks, especially to higher officials of Haramaya University Development Innovation Fund (DIF) for their financial grants. I am also grateful to express my deepest thanks to school principals, teachers’ and students of Dire Dawa Senior Secondary and Abboker Preparatory Schools for their unreserved support and cooperation they provided me during data collection, without which my task could not have been accomplished.
TWO IDEAS OF THE REDOX REACTION:
MISCONCEPTIONS AND THEIR CHALLENGE IN
CHEMISTRY EDUCATION

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Email: barke@uni-muenster.de

ABSTRACT
In interpretations of chemical phenomena students like to mix the macro level of substances with the sub-micro level of atoms, ions and molecules: “water boils at 100 °C and has an angle” – instead of separating properties of substances (water has a special density, freezing-and boiling point) and properties of particles (the H₂O molecule has an angle, H and O atoms are linked by electron-pair bond). For redox reactions students are doing this too: “one Cu²⁺ ion takes two electrons and is reduced to copper” – instead of “to one Cu atom”! Another difficulty seems to be the historical redox definition with the “oxygen transfer”: this idea is so attractive that students argue mostly with oxygen participation instead of the transfer of electrons. This article reflects those misconceptions and proposes ways of instruction to prevent from “school-made misconceptions”. [AJCE, 2(2), February 2012]
INTRODUCTION

In modern chemistry education the redox reaction is defined by an electron transfer, as illustrated with a metal-nonmetal reaction (see Fig. 1), or with the reaction of iron and a copper sulfate solution (see Fig. 2).

---

**Fig. 1:** Model of the reaction of metal atoms with nonmetal atoms by electron transfer (1)

In these examples, the reactions can be explained by electron transfer from metal atoms to nonmetal atoms or of metal atoms on metal ions – it is correctly argued with involved atoms and ions (see Fig. 2):

- Oxidation: $\text{Fe atom} \rightarrow \text{Fe}^{2+} \text{ ion} + 2 \text{e}^-$
- Reduction: $\text{Cu}^{2+} \text{ ion} + 2\text{e}^- \rightarrow \text{Cu} \text{ atom}$
- Redox: $\text{Fe} + \text{Cu}^{2+} \text{(aq)} \rightarrow \text{Cu} + \text{Fe}^{2+} \text{(aq)}$

---

**Fig. 2:** Photo of the reaction of an iron nail with copper sulfate solution, model drawing of the particle view (1)
One other example presents the reaction of potassium iodide solution with bubbles of chlorine gas. The model drawing (see Fig. 3) shows that $\text{Cl}_2$ molecules are reacting with $\Gamma^{\text{(aq)}}$ ions to form $\text{I}_2$ molecules and $\text{Cl}^{\text{(aq)}}$ ions. Electrons are moving from $\Gamma^{\text{(aq)}}$ ions to $\text{Cl}_2$ molecules (see Fig. 3), all $\text{K}^{\text{+}(\text{aq})$ ions are spectator ions: they are not involved in the reaction (2).

![Fig. 3: Model drawing of the reaction of $\text{Cl}_2$ molecules with $\Gamma^{\text{(aq)}}$ ions, $\text{K}^{\text{+}(\text{aq})$ ions remain as spectator ions (2)](image)

If you ask, however, freshmen students at the beginning of their studies in chemistry, one is astonished that mostly the iron-copper sulfate experiment is not reflected on the basis of atoms and ions but of substances: "copper is oxidized to copper oxide and is deposited on the iron nail; iron is oxidized and copper sulfate is reduced; iron is oxidized and takes O from the CuSO₄; electrons are released and oxygen is absorbed" (questionnaire before the lecture in the summer term 2011 at University of Muenster, Germany). On the one hand – rather than with atoms or ions – the students are arguing with substances such as iron and copper sulfate, on the other hand with oxygen in the sense of the historical definition by Lavoisier in 1784. This first definition of
redox processes is so attractive that many learners seek to explain those reactions by oxygen transfer: "O is taken out of CuSO₄."

This paper addresses the question of misconceptions according to the two well known redox definitions and tries to analyze and to compare those erroneous answers. The second part of the paper proposes ways in chemistry education, which should ensure some prevention and challenge regarding the existence of misconceptions (3).

**MISCONCEPTIONS AT THE END OF SECONDARY EDUCATION**

In lessons at the primary level the children are bringing a lot of good observations (3): concerning combustion processes they state: "the fuel disappears irretrievably; some things go into the air (phlogiston?); candles burn totally away; coal glows and leave some ashes behind" (3). Instructing gases and their properties children talk about "gases weigh nothing; even hot air rises up, water evaporates and changes to air; gases are necessary for cooking and heating; gases may explode" (3). Despite good observations, children will not grab the scientific idea without the teacher; they will stay with their *preconcepts*, with their *alternative concepts* from everyday life. The teachers must know those who have preconcepts have to perform good experiments concerning mass comparison of metal and metal oxide portions, should show the density of various gases to help children to change their concept, to realize a "conceptual change" (4). Many other preconcepts concerning combustion, chemical reactions, gases, light, heat, changes of state or particulate nature of matter are described and discussed by Rosalind Driver (5) and Vanessa Kind (6).

Since neither the young people know the historical approach to the explanation of combustion processes by oxygen transfer in oxidation-reduction reactions nor they know from everyday life the concept of electron transfer in redox reactions, a good instruction on these
topics should be successful to grab those scientific ideas. Empirical surveys now show, however, that one can find "home-made misconceptions" or “school-made misconceptions” (4). After an analysis and the knowledge of such ideas, it should be possible to design teaching ways or actions that propose prevention against known misconceptions and convey scientific concepts successfully. Some examples of misconceptions should be referenced. Other misconceptions about basic chemical ideas can be found in articles of Vanessa Kind (6) and Keith Taber (7).

**Redox and oxygen transfer.** In many curricula of schools the oxygen transfer is instructed as the first central idea concerning combustion processes and the participation of oxygen. Hans-Jürgen Schmidt (8) interviewed several thousand students of secondary education, which one of the following reactions should be a redox reaction:

(i) \[ 2 \text{HCl} + \text{Mg} \rightarrow \text{MgCl}_2 + \text{H}_2 \]
(ii) \[ 2 \text{HCl} + \text{MgO} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O} \]
(iii) \[ 2 \text{HCl} + \text{Mg(OH)}_2 \rightarrow \text{MgCl}_2 + 2 \text{H}_2\text{O} \]

About half of the students in grades 10 – 12 chose the correct answer (i). The remaining participants were not sure about this and chose the reactions ii or iii or both (that are acid-base reactions!), and delivered reasons such as: "MgO and Mg(OH)$_2$ contain oxygen, what is absolutely necessary for redox reactions; to any redox reaction O is necessary – so choice (i) cannot be a redox reaction". These students include the syllable “ox” on the participation of oxygen (8) – even if the electron transfer was taught in classes and the oxygen reaction has been declared as a special case of redox reactions.

**Iron-copper sulfate reaction.** Elke Sumfleth (9) examined statements of students in grades 6-13 made to the well known reaction of an iron nail in copper sulfate solution. She documented a lot
of wrong answers, which were based on preconcepts and school-made misconceptions. Above all, students in grades 6 to 8 described the emergence of a copper-colored coat with "settling, hanging or sticking or staining a substance on the iron nail". Interpretations related to everyday life are: "copper sulfate colors the iron nail; copper sulfate sticks on the nail; it stuck, it glues on the nail like color on a piece of wood and then dries up" (9). Half of the seventh-graders suspected an attraction as the cause of the red substance; other students mention an existing magnetism – probably because of the iron nail. These young students just described their observations in other words – you cannot expect scientific ideas.

However, even on the advanced level in grade 10 – 12 there are misconceptions – only interspersed with specialized scientific terms: "copper dissolves from the sulfate and binds to the iron; copper sulfate is reduced; copper atoms attract electrons; iron nails can absorb the ionic solution" (9). These statements demonstrate that special terms of the scientific terminology are indeed learned and the students feel the urge to use them well.

According to the redox idea Vitali Heints (10) developed a new instrument and presented a 15-question questionnaire to students in grades 10 - 12 in some schools of the area of Muenster in Germany. From that questionnaire three problems are taken as examples for this article.

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**Task 1**
An iron nail is dipped into a copper sulfate solution. After one minute, a copper-colored coat is deposited on the nail. Explain the observation.

A total of 34% of participants used the terms redox reaction (oxidation, reduction) and electron transfer, 14% used the terms ignoble and noble metals. Most students took common reaction equations to illustrate the reaction, but they were usually not correct. A large number of correct answers was built along the same line: "copper is more noble than iron, since copper is
firmly set on the iron nail, this means that Cu\(^{2+}\) ions from the copper sulfate solution were reduced, copper was formed by a redox reaction".

More than 60% of responses were classified as defective. In many cases, students do not distinguish between on the one hand, copper and copper sulfate (solution), on the other hand, not substances and particles: "copper ions from the solution connect with the iron nail". Some students of grade 10 were thinking that the metal coating is rust: "the copper-colored material is rust; iron is attacked and there is rust; the nail rusts through the immersion into the copper sulfate solution". Others see the process and result in no reaction as the cause of attraction or in a magnetic interaction: "the nail is magnetic and attracts the sulfate; the copper from the solution is magnetic as the nail".

A "staining, settling or sticking of elemental copper, of the copper sulfate solution, of copper atoms, of copper ions or copper electrons" is suspected in many answers: "the copper particles are deposited on the surface of the nail; copper sulfate solution is saturated and combines with iron atoms on the nail; copper electrons are deposited on the nail and the coating is formed" (10). The data analysis shows that about half of the students are describing their observations by use of familiar every day language.

Students in grades 10 – 12 really show school-made misconceptions, because they do not distinguish between ions and atoms, between atoms or ions and related substances: "copper sulfate is reduced and becomes copper and iron; copper ions from the solution connect with the iron nail; iron (Fe) reacts with copper sulfate (CuSO\(_4\)) and by a redox reaction, the iron takes electrons from CuSO\(_4\) and becomes copper-colored" (10).

For some students it does not seem to be clear that for the emergence of elemental copper, a redox reaction is necessary – in their minds copper is already present in the form of the
element: "copper from copper sulfate solution is deposited on the iron nail, it will combine with iron atoms". The idea of existing ions in salt solutions is missing; those students are mixing substances like copper, copper sulfate solution and iron with their atoms or ions.

**Metal-oxygen reactions.** This second task is determined to show how students describe their ideas on metal-oxygen reactions. In particular, we want to know whether the simple oxygen-definition or the enhanced electron transfer theory is used by the young people, in what cases and to what extent they argue with substances or with atoms, ions or molecules.

**Task 2**
A piece of copper sheet is folded to a small envelope and heated with the roaring flame: the outside of the sheet turns black, after opening the envelope the inside remained copper-colored.

- a combustion reaction takes place, [A]
- the outside is made from black soot, [B]
- a redox reaction occurs, [C]
- copper atoms change their color. [D]

Explain your answer.

With 59% of markings the destructor [B] was the most attractive choice, only 21% gave the right answer [C], [A] and [D] were chosen by 18% and 4%. The popularity of destructor [B], which was combined to a large extent with [A], sometimes with [C], is probably due to the lack of practical experimentation – apparently, many students don’t know the "roaring flame" and what it means. The reasons given for [B] are as follows: "by the flame / through combustion / fire is formed soot, burns outside the copper plate, copper oxidizes, the soot is copper oxide".

Also the role of oxygen for the combustion is not clear for young students, they are looking for everyday life explanations: "oxygen is burned and soot is deposited; oxygen is burned and carbon dioxide is produced, the combustion leads to three products: CO, CO₂, C".

When the advanced students have chosen the right answer “redox reaction”, so they didn’t have outlined any electron transfer or equations partly for electron release and electron acceptance.
Task 3
For the production of iron in the blast furnace iron oxide ($\text{Fe}_3\text{O}_4$) and coal (C) are necessary, by
heating the mixture strongly, the liquid iron is running out with glaring light.
O carbon is a catalyst, [A]
O a redox reaction takes place, [B]
O iron oxide is reduced, [C]
O iron oxide decomposes into elements. [D]
Explain your answer.

Blast furnace process. This task describes the production of iron through the reduction of iron
oxides by coal, which is well treated in nearly every chemistry instruction. The response pattern
is characterized by an almost equal percentage distribution of answers; the correct answer [B]
was only given by 20% of the students, a sufficient explanation by only 4%. By their
explanations almost nobody argued with electron transfer, but usually with “oxygen transfer”
and equations in words, or (often completely wrong) with reaction equations and the “change of
O atoms” like in this equation: $\text{Fe}_3\text{O}_4 + 2 \text{C} \rightarrow 3 \text{Fe} + 2 \text{CO}_2$.

Other reasons are: "coal reacts with oxygen from iron oxide to form CO$_2$, iron is left; by
the carbon combustion oxygen is needed, which is taken from iron oxide". Mostly the answer
[A] was chosen and justified as follows: "carbon only helps to get the reaction going, but it does
not react; carbon supplies the heat that is necessary for the decomposition of iron oxide" (10).

PREVENTION OF HOMEMADE MISCONCEPTIONS
According to the poor results by teaching the redox idea one likes to state: "disregard the
simple redox idea of oxygen transfer from school curricula and school books". Considering that
in so-called oxygen-transfers – for example in the reaction of copper oxide with iron – oxygen
atoms are not transferred, but iron atoms release electrons to copper ions and the oxide ions
change only the ionic lattice, so the emphasis on "the oxygen" is not justified: neither oxygen is
transferred, nor O atoms change their partner. If the redox idea would only be taught as an electron transfer from one particle to another, then instruction and results should improve dramatically.

Historical redox idea. Since this idea is prescribed in all guidelines and school books, one must consider ways of instruction that are touching the extended redox idea as little as possible. There is first the historically evolved definition: teachers or students can refer Stahl’s Phlogiston theory from 1690 and its refutation by the Oxidation theory of Lavoisier in 1784. Students can understand that historically adapted theories have been rejected later and replaced or extended by new theories. In their own classes, they can accept that the extension of the “oxygen transfer” to the electron transfer is legitimate.

On the other hand, in the beginning one could instruct this subject without the word “redox” and use it only in the extended sense. Since oxidation (metal + oxygen $\rightarrow$ metal oxide) and reduction (silver oxide $\rightarrow$ silver + oxygen) are initially defined separately, the redox idea appears dispensable; the notation for the copper oxide-iron reaction is sufficient in this way: iron is oxidized to iron oxide, copper oxide is reduced to copper. Then, if the reaction is described only in words, one cannot get into difficulties with "O atoms, O$_2$ molecules or O$^{2-}$ ions are changing the partner". Choosing a model drawing to show the regrouping of “particles” in the copper oxide-carbon reaction for example, you can explain the "combination of carbon particles with the oxygen particles and the release of copper particles" (Fig. 4).
**Fig. 4:** Model drawing for the reaction of copper oxide with carbon (1)

**Fig. 5:** Macro, sub-micro and representational level in chemistry education (11)

**Extended redox idea.** Successful teaching is possible if the arguments regarding the substances, the smallest particles and the chemical symbols are distinguished from each other. Johnstone (11) created his “chemical triangle” (see Fig. 5) to propose three levels of interpretation: “We have three levels of thought: the macro and tangible, the sub-micro atomic and molecular, and the representational use of symbols and mathematics. It is psychologically folly to introduce learners to ideas at all three levels simultaneously. Herein lay the origins of many
misconceptions. The trained chemist can keep these three in balance, but not the learner” (11). Specially Gabel (12) points out that teachers like to go from the macro level directly to the representational level and that students have no chance to follow this concept: “The primary barrier to understanding chemistry is not the existence of the three levels of representing matter. It is that chemistry introduction occurs predominantly on the most abstract level, the symbolic level” (12).

If we take into consideration that for the extended redox idea all arguments should be done exclusively by atoms, ions or molecules (Fig. 1 and 2: the metal atom emits two electrons, the non-metal atom or the copper ion takes two electrons), and follow all chemistry teaching though the Johnstone-Gabel demand, we may have a better teaching success. Perhaps even model drawings should be drawn by the learner (Fig. 2), and in the first step the names "atom" and “ion” should be involved:

oxidation: \[ \text{Fe atom} \rightarrow \text{Fe}^{2+} \text{ion} + 2e^- \]
reduction: \[ \text{Cu}^{2+} \text{ion} + 2e^- \rightarrow \text{Cu atom} \]
redox: \[ \text{Fe atom} + \text{Cu}^{2+} \text{ion} \rightarrow \text{Cu atom} + \text{Fe}^{2+} \text{ion} \]

After pointing out that not the substances are described by those reaction equations, but the involved atoms and ions, one can change to write those equations without mentioning the names “atom” and “ion” all the time. Another example for writing redox equations and drawing a model picture is the formation of rust by the reaction of iron, water and oxygen (see Fig. 6).
The same is true for acid-base reactions by Broensted (4): not the substance hydrochloric acid is the acid in accordance with the modern definition, but the $\text{H}_3\text{O}^+(\text{aq})$ ions are the acid particles. In pure sulfuric acid the $\text{H}_2\text{SO}_4$ molecules are declared as acid particles, but in diluted sulfuric acid, the $\text{H}_3\text{O}^+(\text{aq})$ ions and $\text{HSO}_4^-(\text{aq})$ ions should be the acids. So if we argue about this issue not with substances but with acid particles and base particles, students can look consequently to all involved particles of an acid-base reaction and can decide successfully which particle is the acid and which particle is the base in the sense of Broensted. Those interpretations would fit to the "Chemical Triangle" – and students would comprehend modern chemistry.

**Fig. 6:** Model drawing of most involved particles in the formation of rust (2)
CONCLUSION

A decision has to be made if the known misconceptions should be included in the classroom lecture to maximize the teaching success. Marco Oetken and Karin Petermann (13) instructed the combustion processes in grade 8 in the way that a cognitive conflict arises. After discussing the alternative concepts concerning combustion, they filled a round flask with a few carbon pieces and with oxygen, and weighed the closed flask on a good balance. Then they heated the flask as strong as possible, the carbon pieces started to burn, and vanished by shaking the flask. After cooling down the flask they could show with the balance an equal mass as before and explained it with the reaction of carbon and oxygen to carbon dioxide (lime water test was made). Finally the carbon-oxygen reaction was shown by model drawings and word equations (see Fig. 4). With those experiments they tried to reach a "conceptual change" in the cognitive structure of their students. They came back to the preconcepts and compared the new scientific model of the carbon-oxygen reaction with all the alternative concepts of the students: "carbon disappears, carbon is gone and the flask weighs less than before". By including those comparisons Oetken and Petermann are convinced that a "conceptual change" will be more successful than without those discussions.
Iron combines with oxygen and water from the air to produce rust. If an iron nail were allowed to rust completely, one should find that the rust weighs...

Less than the nail it came from

The same as the nail it came from.

More than the nail it came from

It is impossible to predict

What do you think?

Fig. 7: Concept cartoon concerning conservation of mass by rusting processes [13]
What is the reason that an iron nail turns red-brown in a solution of copper sulphate?

Iron takes O from CuSO₄, iron oxide sticks on the nail.

Cu²⁺ ions are reduced to Cu atoms, copper is formed.

Iron as a magnetic metal attracts copper.

Copper is leaving the sulfate and precipitates on the

Fig. 8: Concept cartoon concerning the iron – copper sulfate reaction.
Tobias Doerfler (14) taught the topic acids and bases in grade 11, he introduced the neutralization with “beaker models” for hydrochloric acid and for sodium hydroxide solution: \( \text{H}_3\text{O}^+(aq) \) ions and \( \text{Cl}^-(aq) \) ions on one side, and \( \text{Na}^+(aq) \) ions and \( \text{OH}^-(aq) \) ions on the other side. At the end the students described the neutralization with the equation:

\[
\text{H}_3\text{O}^+(aq) + \text{OH}^-(aq) \rightarrow 2 \text{H}_2\text{O}; \text{exothermic}
\]

He pointed out that there is no formation of salt or salt solution, that the other ions are staying unchanged; they may be called “spectator ions”. Finally he took the well known misconceptions into focus and gave one group the incorrect mental model of “\( \text{HCl} \) molecules in hydrochloric acid, \( \text{NaOH} \) molecules in sodium hydroxide solution, a salt formation by the neutralization” (14). The students took those statements and corrected them in the sense of the new gained scientific concept; they applied the new concept to unmask those models as misconceptions. In a second test after working with those misconceptions the results of the test were better than without those discussions (14).

Another way to integrate misconceptions and their correction into lectures is the introduction of concept cartoons (15). Temechegn Engida and Sileshi Yitbarek (16) created those cartoons relating to many topics of chemistry education. Two examples are printed out: with the question according to the masses of an iron nail before and after rusting completely, one student is giving the right answer, three other students are stating wrong mental models (see Fig. 7). For the iron-copper sulfate reaction three persons are telling misconceptions, only one person gives the right answer (see Fig. 8). Students can discuss all answers, should find the right answer, and should correct the three mistakes. Concept cartoons can be presented before starting a topic to diagnose the misconceptions of the students in class: then the teacher knows the ways how his students are thinking, he knows which knowledge exists for starting the topic. The
cartoon should also come into discussion at the end of the topic to summarize the new gained scientific knowledge and to state clearly what is wrong with the presented misconceptions and what is right.

**The end.** The terms oxidation, reduction and redox reactions are central for understanding chemistry – they must be taught best. With the redox idea young people can interpret a lot of everyday life phenomena: combustion phenomena, the rusting of iron and other corrosion processes, the production of iron in the blast furnace, the electrolysis of aluminum oxide melt for aluminum production, the production of electrical energy from batteries and accumulators.

This is to proceed in two steps. In the first step in beginning of teaching burning processes the concepts of oxidation and reduction on the level of oxygen transfer are possible, *substances* are oxidized or reduced. The reactions should experimentally be shown and can be described in word equations and model drawings (see Fig. 4), but not in formulas. One may also think about the term “redox” – it may be omitted in this context.

In the second step, in advanced lectures, the extended redox idea should be taught. With the word “redox” the electron transfer is linked and described by *particles*: metal atoms are oxidized to ions, other ions are reduced to atoms. Part equations for oxidation and reduction should show the number of transferred electrons, model beakers or model drawings may visualize those chemical processes (see Fig. 2 and 3). With the sequence “macro → sub-micro → symbolic” (see Fig. 5) not only redox reactions can be taught successfully, also acid-base reactions and complex reactions! And don’t forget to integrate misconceptions into lectures: the students know with those discussions what is right and what is wrong!
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ORGANIC REACTION MECHANISM CONTROVERSY: 
PEDAGOGICAL IMPLICATIONS FOR CHEMICAL EDUCATION

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ABSTRACT
The paper investigated the pedagogical implications of the controversy generated by the nature of reaction mechanism in organic chemistry as to whether it can be proven or not. A conference of a chemist, chemical educator, a graduate chemistry teacher and a graduate assistant was organized. The conference lasted for four weeks of two interactions per week. Each interaction took three hours. Interactions during the conference took a total of 24 hours (8x3). A postgraduate student recorded minutes of each interaction. The minutes of the total interactions served as the source of information for the discourse in the study. While the chemist treated reaction mechanism as a fact supported by experimental evidences, the chemical educator was conscious of reaction mechanism as a theory which can be refuted. The students were not sure of the nature of reaction mechanisms. These were discussed in the study presented below. [AJCE, 2(2), February 2012]
INTRODUCTION

Chemical reactions are common in chemistry and related disciplines. In fact, chemists study chemical reactions. Chemical reactions can be simple or complicated to understand. For example, a reaction that simply goes from A to B or from B to A may be easy to understand. However, there are so many chemical reactions notably in organic chemistry where reactions may not directly lead to products. Some complexes may form between reactants and products which will make it difficult to understand reaction pathways to products.

Khan and Khan (1) defined reaction mechanism as “a step-by-step description of the events taking place in a chemical reaction”. It is a theoretical framework accounting for the fate of bonding elections and illustrates which bonds are broken and which are formed. For example in the chlorination of methane to give chloromethane:

\[
\begin{align*}
\text{Cl}_2 & \rightarrow \text{Cl} + \text{Cl} \text{ (Initiation, homolytic fission of the chlorine molecule)} \\
\text{Step 1:} & \quad \text{Cl} + \text{CH}_4 & \rightarrow & \text{CH}_3\text{Cl} + \text{HCl} \\
\text{Step 2:} & \quad \text{CH}_3\text{Cl} + \text{Cl}_2 & \rightarrow & \text{CH}_2\text{Cl}_2 + \text{Cl} \\
\text{Step 3:} & \quad \text{CH}_3\text{Cl} + \text{Cl}_2 & \rightarrow & \text{CH}_2\text{Cl}_2 + \text{Cl} \\
\end{align*}
\]

and so on leading to a mixture of all the possible chlorination products. This is simple and straightforward, but how do you prove to the students the existence of free radicals involved in the mechanism?

A little more complex example is the dehydrogenation of an alkyl halide to yield more than one alkenes, namely:
Steps in the production of the alkenes are not of interest here, but the direction of the curved arrows and the formation of bonds. There are concepts that support these ideas but can they be proven to the understanding of the learner? Clugston and Flemming (2) in discussing the relationship between order and reaction mechanism described reaction mechanism as a detailed step-by-step account of how an overall reaction happens. It specifically indicates all intermediate states and mentions all intermediate species formed, even though some do not appear as products. Information about orders of reactions is derived from experimental data.

In this sense, reaction mechanisms are studied. Generally, chemical reactions involve breaking and making of bonds between atoms and molecules, and possible realignment of atoms, ions and molecules. A chemist is particularly interested in reaction mechanisms which are the totality of what happens during chemical reactions. The chemist takes an anatomical view of what happens during chemical reactions: what bonds were broken? What bonds are formed? Is there a complex that is formed before product? What realignment of atoms, molecules and ions are noticed including free radicals?

Of recent, reaction mechanisms have been of concern to chemical educators. The pedagogical issue is that we should be mindful about what we teach the students. When real
situation is mentioned in passing instructions to a novice, one can concretize such situation for meaningful understanding and learning. For example, telling a chemistry student and showing him a sample of copper II tetraoxosulphate VI will help him. But telling the student about an atom or ion and showing the student a model of such- as is the case of chemistry: Green and Rollnick (3)-will not help. This is because the model is not an atom or ion. In this context, reaction mechanisms in chemistry textbooks that we teach the students have come under serious criticisms.

One of such criticisms is that of whether or not reaction mechanism can be proved. Chemists are satisfied with the study of reaction mechanism as provided by the chemistry syllabus or course work. Chemical educators are worried about rote learning that will result from the chemists’ point of view. Some controversy has arisen that need to be properly examined.

THE CONTROVERSY

Controversy is likened to an argument that is generated by individuals’ various suggestions and opinions about an issue. The very nature of a controversial issue is that there is more than one defensible position that can be taken (4). When dealing with controversial issues it is important to uncover how particular knowledge claims may serve the interests of different claimants. Reaction mechanism is one such issue in organic chemistry that has attracted a lot of controversial comments from some members of the scientific community. Most organic chemistry textbooks commonly teach that reaction mechanisms can never be proven. But Buskirk and Baradaran (5) have reasons to argue that reaction mechanisms can only be proven false. They further argued that there is a philosophical limitation on our ability to prove chemical
reaction mechanisms. According to them, “mechanisms cannot be proven with philosophical certainty”.

Brown (6) considered reaction mechanisms from its theoretical point of view. He posited that a theory that has been tested by many different experiments that could have in principle proven it to be incorrect is a better explanation for having been so tested. He concluded that it is possible to devise a useful confirmatory experiment for a reaction mechanism considering the general form of the potential energy surface over which a chemical reaction proceeds.

Lewis (7) focused on the general nature of proof as providing absolute certainty of truth. According to him, most professional chemists use the legal definition of proof when they accept evidence for or against a particular hypothesis or theory. He suggested that at some point, the experimental (circumstantial) evidence in favor of the mechanism under study becomes overwhelming, and at that point one might argue with considerable justification that the mechanisms have been proved beyond a reasonable doubt. He seems to be saying that failure to be falsified by repeated experiments is one hallmark that is used to elevate a hypothesis to the status of a theory, and in this aspect a well-tested reaction mechanism is more akin to a theory than a hypothesis.

Yoon (8) drew our attention to Thomas Kuhn’s philosophy that the value of a scientific theory rests upon its ability to predict future outcomes. Theories that are supported by repeated experimental validation become accepted as paradigms which succumb to falsification only with great difficulty. Yoon (8) opined that experimental chemists perform experiments designed to corroborate mechanistic hypothesis. He argued that techniques such as molecular beam and femtosecond spectroscopy allow us to gain insights into reaction mechanisms that were inaccessible using classical kinetic methods alone. There is no amount of technological
sophistication that will limit our insight to the over abundance of possible alternate explanations for any given discrete data available for probing reaction mechanisms.

As part of the controversy by the question: “Can reaction mechanisms be proven?” Wade (9) declared in categorical terms that:

“I take strong exception with Buskirk and Baradaran’s premise that mechanism can now be proven – the current usage of well-established seems to Buskirk and Baradaran’s suggested use of proven. However, it is my opinion that exchanging “proven” for “well-established” is a step backward in science. I plan to continue accepting mechanisms as well-established but not provable and doing chemistry rather than philosophy”.

Chemists, educators and students are entitled to their mental constructs about reaction mechanism in the classroom. What pedagogical implications have these knowledge claims for teaching and learning reaction mechanisms in organic chemistry? This is the main interest of the paper. Thus three questions were critically considered in the paper, namely:

(1) What is the view of the chemist on the nature of reaction mechanism?

(2) What does the chemistry teacher think about teaching and learning reaction mechanism?

(3) How do the students feel about learning reaction mechanism?

**METHODOLOGY**

A face-to-face conference of chemists, chemistry teachers and students was organized to discuss the nature of reaction mechanism and implications for science education. A professor of organic chemistry, a professor of science education, a graduate chemistry teacher (who has had the experience of teaching senior secondary students for eight years), a graduate assistant pursuing a master’s degree in an aspect of organic chemistry and two final year chemistry students (specializing in organic chemistry) were invited for the conference. The exercise
spanned a period of four weeks with circulars for a meeting sent to participants eight times. Each conference meeting lasted for three hours.

The investigator started the initial discussion with the argument of Brown (6), Lewis (7), Yoon (8) and Wade (9) on the question asked by Buskirk and Baradaran (5), namely “Can reaction mechanism be proven? Participants brainstormed on the following sub-questions, namely:

(i) What is reaction mechanism?
(ii) What evidence exists for acceptance of reaction mechanism?
(iii) How do we learn reaction mechanism?
(iv) What are the contributions of theories to reaction mechanisms?
(v) What facts are associated with reaction mechanisms?
(vi) How do chemists arrive at reaction mechanisms?
(vii) Can we prove reaction mechanisms?

The professor of organic chemistry provided an insight into reaction mechanism in organic chemistry and guided our discussions to conceptions and misconceptions as thought by the other participants. The professor of science education was particularly interested in the pedagogical implications arising from the controversy of teaching and learning reaction mechanisms. The graduate assistant, chemistry teacher and final year chemistry students were involved in the discussion to express their views about learning reaction mechanism after hearing from the chemist and the science educator. The chemistry teacher apart from presenting his view was also requested to make suggestions as to what he thought should be done to help students learn reaction mechanism. A postgraduate science education student was invited to take minutes
for each session and also acted as the rapporteur. Altogether the postgraduate student recorded eight comprehensive minutes which formed basis for the discourse.

FINDINGS

Excerpts emerging from the discussion of the chemist, chemical educator and the graduate chemistry teacher concerning reaction mechanisms were carefully examined and presented, thus:

Chemist:

Reaction mechanism, we chemists know, is central to learning how things work in chemistry. … I mean fundamental concepts associated with formation of radicals, release and acceptance of electrons, bond breaking and making must be known. Even when experiments are carried out and analyses done, we need extra knowledge to understand what is going on. Ascertaining reaction mechanism is the project of a chemist, carried out over a period of time and found to be reliable.

Chemical educator:

There are numerous chemistry textbooks for teaching and learning. … The books have their different interpretations for reaction mechanisms. … Reaction mechanisms by Peter Sykes is a good one…We don’t teach students how to prove reaction mechanism; rather they learn it. … Most students can’t grapple with the associated concepts; they memorize and do a lot of guess work.

Graduate chemistry teacher:

Students are taught to define reaction mechanisms. … What they learn is limited in their syllabus and nothing more; mechanism is quite difficult for students.

It was noted from the interactions in the recorded minutes of the conference that:

(i) The chemists’ emphasis was on the content of chemistry. He talked more about facts, concepts, principles and laws. He harped so much on the experimental evidences supporting reaction mechanisms. He talked about the ability of the students to apply the theories
associated with reaction mechanisms. The chemist emphasized the rigid principles governing reaction mechanisms based on the theoretical nature of reaction mechanism. “Even though what transpire in between the complexes are not visible to our eyes, there are crown evidences that they happen” the chemist stated.

(ii) The chemical educator was particularly conscious of the teaching aspects of reaction mechanism. He stated that reaction mechanisms could be taught according to the chemistry course content and as contained in current chemistry textbooks, but chemistry teachers should watch out for current information in journals and internet with the view of making changes. He continuously sighted some scientific philosophies of Thomas Kuhn and Karl Popper concerning paradigm shift and fallibilism. The main concern of the chemical educator was that students will end up “learning to pass examination-related reaction mechanism and not understanding what it was all about”. The chemical educator was particularly interested in the theoretical nature of reaction mechanisms. He stated that students need to learn it and meaningfully understand it the way it is. He noted the difficulties students encountered in learning kinetics which is important in determining reaction mechanisms. He stated that kinetics is the best tool for predicting or eliminating mechanisms under consideration since an observed reaction rate must satisfy the proposed mechanism.

(iii) The graduate chemistry teacher did not say much about the teaching of reaction mechanism at the senior secondary school level. Our interactions in the conference showed that he had some knowledge of reaction mechanisms having obtained a degree in chemistry education in one of the best universities in Nigeria. The graduate assistant was regarded as a chemistry student. The graduate chemistry teacher, graduate assistant and final year chemistry students’ views were taken as those of chemistry students. Our interactions with them in the
conference showed that they did not find it easy learning reaction mechanisms. The students showed good understanding of reaction mechanisms and constantly sighted textbooks to prove that they knew what they were saying. When confronted with the question: “Do you think that the mechanisms can be proved”, they followed with question. “How? “We learnt it the way it is in the textbook” was their answer. Further argument showed that they were satisfied learning reaction mechanism as a fact and not a theory.

THE DISCOURSE

As a chemistry student, I was particularly interested in memorizing reaction mechanisms so as to pass related chemistry courses without understanding the nitty-gritty of such mechanisms. I guess that there are so many chemistry students that were like me and even today many chemistry students do not understand reaction mechanisms. As a chemistry teacher and an educator, I look back at those days and recall all the pains and efforts made to understand reaction mechanisms and the problems my students will have to grapple with direction of arrows and either electrons grabbed or shared with atoms or ions. I also try to imagine how my students feel about the breaking and making of bonds as related to electrons. Discourse of Green and Rollnick (3), Sykes (10), and Bhattacharyya and Bodner (11) on these issues lend credence to my experiences and observations. The graduate assistant and the chemistry teacher that participated in the conference corroborated these experiences in their views.

One of the aims of the chemistry syllabus is to provide adequate foundation for post-secondary chemistry course (WAEC, 12). In this regard, some elements of reaction mechanism in organic chemistry included in the syllabus are simply examples of addition and substitution reaction, properties of the – OH group as functional group, inter-convention of the various forms
of carbohydrates to mention a few. These impose high cognitive demand on the students. Interactions with the students that participated in the conference showed that their reasoning at the abstract level was limited. It was also gathered that not all the students taking such chemistry courses requiring mechanisms are at the formal abstract level of gazing into space to make out how bonds are formed and how bonds are broken.

It is worth noting that tertiary teachers have problem in teaching reaction mechanisms. Without doubt students’ difficulties in learning and understanding reaction mechanism will arise from the teachers’ handicap. Teaching reaction mechanism will require teachers’ thorough knowledge of: (i) theoretical basis of reaction mechanism, (ii) experimental basis of reaction mechanism, (iii) facilities available for studying reaction mechanism, and (iv) students’ readiness to learn reaction mechanism. These issues are considered as part of the teachers’ pedagogical content knowledge-distinctive body of knowledge for teaching and as the professional knowledge base of teachers (13).

A chemical educator has the training of a chemist and that of an educator. An effective chemistry teacher must be armed with the content and process of chemistry. The teacher must also posses the adequate pedagogical know-how to be able to impart knowledge in the content and process area. Part of the course taken by the chemical educator in training is the “History and philosophy of Science and Science Teaching”. The course is designed to acquaint the trainee chemistry teacher with contemporary views of the nature of science and scientific inquiry, and to relate these views to issues concerned in the teaching of science in schools and the school curriculum. Particular emphasis is given to the viewpoints advanced by various philosophers of science and the role such philosophical consideration should play in the professional training of science teachers including chemistry teachers.
Wade (9) has emphatically stated that chemistry is not philosophy; chemistry should be taught as chemistry, and philosophy as philosophy. In rationalizing and justifying theories in chemistry, philosophical knowledge is relevant. For example, central to reaction mechanisms is the transition state theory. This theory is applied to the activated complex or the transition state. It makes use of the concepts of equilibrium constant and free energy. As related to the study of reaction mechanisms, the activated complex is regarded as being like a molecule even though its lifetime is very short, and it cannot be studied as a chemical species. In spite of this, the idea of thinking of the activated complex as being in equilibrium with the reactants proves useful (14).

Another useful theory in reaction mechanism is the collision theory of reactions. This theory states that molecules must physically meet before they can react and that molecules must collide with sufficient energy for reaction to take place. The teacher must understand and know how to apply these theories in order to relate them properly to reaction mechanism.

According to the chemist (professor of organic chemistry), during the conference emphasized that these theories were guiding principles in studying reaction mechanism. Students have to learn them the way they are so as to understand reaction mechanism. Reaction can be conceived through experimental evidences but cannot be proved. If this is the case, how will a teacher grapple with the issue of convincing the students?

Buskirk and Baradaran (5) despite all the modern techniques that provide macroscopic evidences about reaction mechanisms recognized the pedagogical problems associated with unproven nature of reaction mechanisms philosophically and suggested that:

“It is important to remind students that reaction mechanisms are theories not facts. They should not be believed dogmatically and are open to refutation by later work. We fear, however, that the idea that mechanisms can never be proven or even supported by evidence will discourage students from using all the tools at their disposal. We should continue to encourage students to seek confirmation of their mechanistic hypothesis and use theories for which there is the most support”.
A conscientious teacher should have to rethink about the currency of his/her chemical knowledge. One useful thing about the philosophy of chemistry, like any other science discipline, is that it seeks the justification of the status of theories in teaching and learning processes. Theories are central in development and growth of scientific knowledge, including chemical knowledge. Facts are important but we must remember they are theory-laden as we are told by Karl Popper. Hypotheses are constructs that form part of the development trend of theories. We have also been told that successful theories are continuously facing threat from possible crisis in the chemical society like any other scientific community. As teachers, we still make our students to depend on induction and recognize that successful tests of theory constitute support for it. We also believe that observations are theory-laden just as facts. So whenever we make an observation, we rely on theories and assumptions beyond those that we are testing.

Reaction mechanisms are mental constructs derived from experimental evidences about how a reaction proceeds. These mechanisms as we know in chemical reaction lend themselves to alternative pathways depending on which reagents are involved. However, what is of interest is not the effect of the reagents but the mechanism as bonds are broken and made related to electron transfer, acceptance, rejection, atom and charges. The implication of this is that for the purpose of learning and understanding, the teacher uses a model to illustrate issues related to reaction mechanisms. Such models do not portray reality rather they serve as “instructional way out” of the problem for the teacher. This is the conviction of the teacher which gives him the confidence to continue giving instruction of the reality of reaction mechanisms equivalent to proveness of reaction mechanisms. To what extent can we convince the learner chemist for meaningful learning as to proving reaction mechanisms to be true? On the other hand, will instructions benefit the learner if we continue to refute existing reaction mechanisms for the sake
of knowledge? Is this built into the framework of the course outline of the students in the related chemistry course? The choice is clear-teaching chemistry or teaching philosophy. We do know that the essence of philosophy of science is to enhance rational understanding of chemical principles. Of what use will it be to the teacher especially in the case of proving the efficacy of a reaction mechanism of reactants to products?

CONCLUSION

Chemistry teachers teach reaction mechanisms as in textbooks using guiding principles students may understand or not. At the advanced level experimental evidences are presented to learner to support reaction mechanisms. The student is interested in passing related examinations without meaningful understanding. Students are not interested in finding out whether reaction mechanism can be proven or not. Chemists do not concern themselves with the proven nature of reaction mechanisms as long as there are guiding principles for learning them. The controversy arising from the proven nature of reaction mechanisms will persist. We may need to tow the line of the chemical educator who insists on currency of information regarding reaction mechanism because of pedagogical implications.

REFERENCES

SYSTEMIC ASSESSMENT AS A NEW TOOL FOR ASSESSING STUDENTS LEARNING IN CHEMISTRY USING SATL METHODS:
Systemic True False [STFQs] and Systemic Sequencing [SSQs] Question Types

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ABSTRACT
Systemic assessment [SA] has been shown to be a highly effective new vehicle in raising the level of students academic achievements, increasing equity of students learning outcomes, improving students’ ability to learn by enhancing the process of teaching and learning, and involving the student as an active participant in this process. Systemic assessment questions (SAQs) are the building units of systemic assessment which measures the students' ability to correlate between concepts and to discover the new relations between concepts. In this paper we illustrate two new types of SAQ, namely, systemic true false questions [STFQs], and systemic sequencing questions [SSQs]. [AJCE, 2(2), February 2012]
INTRODUCTION

The systemic approach to teaching and learning (SATL) which was first described in 1998 (1-6) helps learners to deduce new relationships among concepts that enrich the operation of teaching and learning using elements of the cognitive, psychomotor, and emotional domains. We have proposed systemic assessment (SA) of learners to produce a more efficient evaluation of the systemic-oriented objectives in the SATL techniques and as an effective tool for assessing students' meaningful understanding of chemistry topics at the secondary and tertiary levels (7, 8).

Recent studies indicated that SAQs are valid and reliable evaluation tools for 11th grade high school students. SAQs consider several concepts at once applying them in a new situation which requires the synthesis of a comprehensive answer (9).

Here we continue our work on systemic assessment to assess students' academic achievements in chemistry using systemic multiple choice questions [SMCQs], we illustrate here another type of SAQs, namely, systemic true/false questions [STFQs] and systemic sequencing questions (SSQs).

Why Systemic Assessment?

Systemic assessment (SA) has the following advantages:

i. it measures the cognitive structure from the quantitative through the qualitative (domains);

ii. assesses students’ higher-order thinking skills where they are required to analyze, synthesize, and evaluate;

iii. measures the students’ ability to correlate between concepts;

iv. enables the students to discover new relationships among concepts;
v. gives the students rapid feedback during the term about how well they understand the course material;

vi. assesses the students in a wide range of concepts in the course units;

vii. measures the systemic intended learning outcomes (SILOs) beside linear intended learning outcomes (LILOs)

viii. develops the ability to think systemically, critically, and creatively, and to solve problems;

ix. very easily scored;

x. is objective, realistic and valid.

**SYSTEMIC ASSESSMENT QUESTIONS [SAQS]**

SAQs are the building questions of any systemic assessment [SA], namely, systemic multiple choice questions [SMCQs], systemic true-false questions [STFQs], systemic matching questions [SMQs], systemic sequencing questions [SSQs], systemic synthesis questions [SSyQs], and systemic analysis questions [SAnQs].

**Requirements for building Systemic Assessment**

We start with content analysis of the course units into concepts and the related knowledge skills and attitudes. Then determine the type of relationship that exists between the given concepts, the size of the building systemic [triangular, quadrilateral, etc.], and finally choose the type of the systemic assessment questions [SAQs].

**Geometric Forms of Systemic Assessment Questions (SAQs)**

The systemic are the building units of the SAQs and these take various geometric shapes such as triangular, quadrilateral, pentagonal, hexagonal, etc., depending on the number of
concepts that are incorporated in the diagram (Figure 1)(6, 7). We take into consideration the following points when we build this type of question.

1- Concepts or facts are placed at the corners of these diagrams:

2- We use the sides of these diagrams as arrows pointing to the relationships between concepts or facts.
3- The head of arrows could direct clockwise or anticlockwise.

Type I: Systemic True False Questions [STFQs]

STFQs are well suited for testing student comprehension, synthesis and analysis, and require a student to assess whether a systemic is true or false. The advantages of STFQs are:

- Students can respond to many STFQs covering a number of concepts and facts and their relationships in a short time.
- Students can be assessed of their higher-order thinking skills to analyze, synthesize, and evaluate,
- Teachers can easily score STFQs.

Examples

The following examples are intended to illustrate how STFQs have been and can be used in Chemistry.
Q-1-Indicate which of the following systemics are true (T) and which are False (F):

a) (     )

i) C₆H₅NSO₃
ii) HCl

Br₂/dioxan
-5°C

H₂SO₄

a) (     )

ii) HCl

b) (     )

i) AcONO₂
ii) Pyridine

heat
200°C

HNO₃

b) (     )

c (     )

Ac₂O,
SnCl₄

AcONO₂

Wolff
kishner
red.

K₂Cr₂O₇/
H₂SO₄

H₂/Ni-CO

Δ

K₂Cr₂O₇/
H₂SO₄

NaBH₄

NaBH₄

K₂Cr₂O₇/
H₂SO₄

Δ

NaBH₄

Δ

H₂/Ni-CO

d) (     )

Answer: True systemics are (a & c); False systemics are (b & d)
Q-2-Indicate which of the following systemics are true (T) and which are false (F):

1)

\[ \text{displacement decreases} \]

2) 

\[ \text{electrophilic displacement decreases} \]

3) 

\[ \text{nucleophilic displacement increases} \]

4) 

\[ \text{N-alkylation decreases} \]

Answer: True systemics are (2 & 4); False systemics are (1 & 3)
Q3-Indicate which of the following systemics are true (T) and which are false (F):

Answer: True systemics are (b & c); False Systemics are (a & d)
Q4-Indicate which of the following systemics are true(T) and which are false(F):

Answer: True systemics are (b & c); False Systemics (a & d)

For more examples, see (10 and 11)
Type 2: Systemic Sequencing Questions [SSQs]

SSQs require the student to position text or a formula in a given sequence of a systemic diagram; these kinds of systemics can assess higher-order thinking skills.

Examples

Q1-Arrange iron and its related compounds in the correct places of the following systemic diagram:

\([\text{Fe, FeCl}_2, \text{FeCl}_3, \text{Fe}_2(\text{SO}_4)_3]\)

Answer:
Q2-Arrange calcium and its related compounds in correct places of the following systemic diagram:

[CaO - Ca - CaCO3 - CaCl2 - Ca(OH)2]

Answer:
Q3-Arrange the given organic compounds in the correct places of the following systemic diagram:

\[ \text{[CH}_2\text{=CH}_2, \text{ C}_2\text{H}_5\text{OH, CH}_3\text{CH}_2\text{Cl, CH}_3\text{CH}_3, \text{CH}_3\text{COOH]} \]

Q4-Arrange the given heterocyclic compounds in the correct places of the following systemic diagram and complete the reaction conditions for the process.
For more examples, see (10 and 11)

REFERENCES

ABSTRACT

A triangle divided in three parts was used to relate three variables, or two variables and a constant. Students learned to manipulate a given equation so that one of the variables is a product of the other two variables. Problems relating density, mass, and volume; speed of light, frequency and wavelength; gram, mole, and molar mass, molarity, moles and liters; and number of particles, Avogadro’s number, and mole were attempted using triangles. In addition, a special triangle was constructed to relate the variables and a constant of the ideal gas law equation, and was used to solve ideal gas law problems. This visual representation of the problem helped students to understand the factors that need to be considered and the operations that needed to be performed in the problem-solving process. Over the course of two years, the method was used in four different introductory chemistry classes that had a total of 87 students. More than 80% of the students who use triangles were able to arrive at the correct answers. A big percentage of students also liked using triangles to solve simple problems. [AJCE, 2(2), February 2012]
INTRODUCTION

Learning chemistry is a challenge for many beginning college students. For one thing, it involves learning the vocabulary, underlying facts, and associated concepts of the field, which requires more than mere memorization. In addition, a good knowledge of algebra is needed to manipulate and solve some simple problems. Often, students who take introductory chemistry courses find it difficult to apply the math they already know from high school, or worse, the basic math skills are lacking altogether. It is not uncommon to find students who will pull out a calculator when asked to multiply 1.1 by 5 or to divide 2.4 by 2. Students also try to memorize how a particular problem has been solved, instead of concentrating on working several related problems at the end of each chapter until they master a required problem-solving skill.

To compound this problem, many freshmen have poor time management skills. They can be slow to realize that the amount of work required in college in order to become successful is exponentially higher than that in high school and that time spent learning outside of class is as important as that spent in the classroom. Another issue impacting time management is the lure of social networking tools. Learning (in and out of the classroom) competes with texting, tweeting, and connecting with friends in social networking sites. All of this interference with learning can result in students who lack focus, skip class, or never realize that they missed class at all. When several of these issues are going on at the same time, those students quickly get overwhelmed by the required work of the course. They end up wanting the instructor to slow down and to be “gentle” when grading their work.

When we consider then that students may come to our introductory chemistry classes with low math skills, inadequate problem solving skills, unrealistic expectations about effort, and poor study habits, it is no wonder that instructors are confronted with huge obstacles in helping
students to succeed in freshmen chemistry classes. Oftentimes, students who fail their initial chemistry, which for this report will be termed “CHEM 101”, never come back to retake the course. The challenge then is to make them successful, because if they don’t pass the first time, they will abandon the subject. CHEM 101 is taken by the majority of students in sciences, health related courses and in engineering, but for some, CHEM 101 will be the only chemistry they take in their entire lives, so it is very important that they at least learn a few basic skills in this course.

Because of a growing awareness of (and concern about) these challenges, a strategy that I have found effective in freshmen chemistry classes is “Communication Notes.” The main objective of Communication Notes is to remind and to reinforce what has been covered in class; and four e-mails messages a week are sent out to all CHEM101 students. A few facts, and drills similar to problems provided as examples in this paper, are repeated several times with the hope that they will become second nature for students when encountered during the course of study. A big advantage of this approach is that no significant amount of class time is used up. Minor questions and issues, if any, are usually discussed during the first two minutes of each following lecture.

The use of a triangle first learned in high school, is emphasized in solving problems involving three variables, since the majority of the problems in introductory chemistry, with the exception of the ideal gas laws, can be solved by manipulating equations that contain three variables. The visual representation of the problem helps math-challenged students to understand the factors that need to be considered and the operations that need to be performed in the problem-solving process.
The difficulty of teaching beginning chemistry students unit analysis problems (1) and stoichiometry (2) has been previously addressed. Blending English and math and not mere equations has also been suggested as a useful tool for student learning (3). Dimensional analysis is commonly used to help students arrive at a required answer by tracking units, and has its advantages and disadvantages.

In this paper the use of a triangle to solve three variable problems is presented as a useful technique for beginning chemistry students. Problems similar to those presented in this paper are sent out to students by email during the time when each topic is being covered in class.

THE TRIANGLE METHOD IN CHEMISTRY

One of the first equations students encounter is one relating density, mass and volume. Students are told that density is mass per unit volume, and in mathematical terms,

\[ \text{Density} = \frac{\text{mass}}{\text{volume}} \]

The following questions test the handling of the expression. What happens when the density and the volume are given and one is asked to find the mass; or, the density and mass are given, and the finding the volume is the task? Using simple algebra, mass can be expressed as density x volume, and volume as mass divided by density. At that point students think that they are faced with learning three different equations.

It is important to emphasize that they do not have three different equations; that it is only one equation, and that, that equation can be used to find an unknown when two variables are given. The following triangles, one using variables and the other, the corresponding units, can be used for solving problems involving density, mass, and volume.

\[ \text{Density} = \frac{\text{Mass}}{\text{Volume}} = \text{grams/mL or grams/cm}^3. \ 1 \text{ml}=1\text{cm}^3; \ 1/\text{cm}^3 = \text{cm}^{-3}. \]
The horizontal lines in the figures represent division, and the vertical lines represent multiplication. Thus, mass = density x volume (g = grams/cm³ x cm³); volume = mass/density (cm³ = grams/grams.cm⁻³); and density = mass/volume (g/cm³). Looking closely at the units in the triangle, we realize that multiplying the two units below the horizontal line yields the unit above that line. Another way of writing g/cm³ is g.cm⁻³.

a) \[ g\cdot\text{cm}^{-3} \times \text{cm}^3 = g \]

b) \[ g/\text{gcm}^{-3} = \text{cm}^3 \]

We can also think about units as if as they were numbers. Let us visualize this using the triangle below.

Using the numbers in the triangle,
Two numbers, \( \frac{1}{2} \) and 2 can be multiplied to yield 1. Also note that \( 1 + \frac{1}{2} = 2 \).
In summary, to get 1, multiply \( \frac{1}{2} \) by 2; to get \( \frac{1}{2} \) divide 1 by 2; and to get 2 divide 1 by \( \frac{1}{2} \).

**Examples**

1. The density of mercury (Hg), the only metal that is a liquid at room temperature, is 13.6 g/mL. Calculate the mass of 16.50 mL of the liquid.
Mass (g) = density (g.cm\(^{-3}\)) \times \text{volume (cm}^3\). Note that 1 mL = 1 cm\(^3\).

Mass = 13.6 g.cm\(^{-3}\) \times 16.50 cm\(^3\) = 2.24 \times 10^2 \text{ g}.

2. Bromine is a reddish-brown liquid. Calculate its density if 283 g the substance occupy 94 mL.

\[\text{Density} = \frac{\text{g}}{\text{cm}^3}.\] Remember that 1 mL = 1 cm\(^3\).

Therefore density = \(\frac{283 \text{ g}}{94 \text{ cm}^3}\) = 3.0 g/cm\(^3\).

3. The density of water is 1 g/cm\(^3\). What is the volume 5 g of water?

\[\text{Volume} = \frac{\text{g}}{\text{g.cm}^3}.\]

Volume = \(\frac{5 \text{ g}}{1 \text{ g.cm}^3}\) = 5 cm\(^3\), or 5 mL, since 1 mL = 1 cm\(^3\).

**Problems involving Avogadro’s number**

In the SI system the mole (mol) is the amount of a substance that contains as many elementary entities (atoms, molecules, or other particles) as there are atoms in exactly 12 g or 0.012 kg of the carbon-12 isotope. The actual number of atoms in 12 g of carbon-12 is determined experimentally. This number is called Avogadro’s number (\(N_A\)), in honor of the Italian scientist Amedeo Avogadro. The currently accepted value is \(N_A = 6.0221415 \times 10^{23}\). Generally, we round it to \(6.022 \times 10^{23}\). Thus, just as one dozen of pencils contains 12 pencils, 1 mole of copper atoms contains \(6.022 \times 10^{23}\) Cu atoms.

Finding the number of particles (atoms, molecules or ions) in stuff requires us to know Avogadro’s number (\(6.022 \times 10^{23}\)) and the number of moles (amount) of stuff.

1 mole contains \(6.022 \times 10^{23}\) particles

2 moles contain \(2 \times 6.022 \times 10^{23}\) particles

10 moles contain \(10 \times 6.022 \times 10^{23}\) particles, etc.
We see an important relationship developing here.

Number of particles = Avogadro’s number x moles.

Particles = $N_A \times \text{moles}$. The following triangle can also be used.

![Figure 4](image)

**Figure 4**

**Gram-mole conversions**

Grams = moles x molar mass = moles x grams/mole.

Moles = grams + molar mass = grams / grams/mol$^{-1}$.

Molar masses in grams/mole are what we get from the periodic table of elements, so we focus on using that quantity to move from moles to grams and vice versa.

![Figure 5](image)

**Figure 5**

**Examples**

1. Sulfur (S) is a nonmetallic element that is present in coal. When coal is burned, sulfur is converted to sulfur dioxide and eventually to sulfurous acid that gives rise to the acid rain phenomenon. How many atoms are there in 12.5 g sulfur?
Solution: There is g and mol in Fig. 5, so starting from grams, the number of moles can be found, followed by finding the number of particles by using Fig. 4. Let us use Fig. 5 first to find the number of moles. Figure 4 will be used to find the number of atoms (particles).

Using Fig. 5, we need to get the molar mass of sulfur from the periodic table of elements, which is 32.07 g/mol. G/mol can be written as g.mol\(^{-1}\).

\[
\text{Mol} = \frac{g}{\text{g.mol}^{-1}}
\]

\[
\text{Mol} = \frac{12.5 \text{ g}}{32.07 \text{ g.mol}^{-1}} = 0.391 \text{ mol.}
\]

We now move to Fig. 4 to find the number of atoms.

\[
\text{Atoms (particles)} = \text{Avogadro’s number (Na)} \times \text{mol}
\]

\[
\text{Atoms} = 6.022 \times 10^{23} \times 0.391 \text{ mol.}
\]

\[
\text{Atoms} = 2.36 \times 10^{23}.
\]

2. What is the mass of 4.70 \times 10^{24} atoms of Cr?

Solution: The first thing we need to do is to find the number of moles using Fig. 4. A little inspection indicates that since Avogadro’s number is 6.022 \times 10^{23}, the number of moles in the problem will be greater than one. Using the periodic table we know that the atomic mass of Cr is 51.9961 g/mole.

Using Fig. 4, the number of moles = Particles \div \text{Avogadro’s number}

\[
\text{Number of moles} = \frac{4.70 \times 10^{24} \text{ atoms}}{6.022 \times 10^{23} \text{ atoms.mol}^{-1}} = 7.80 \text{ mole.}
\]

Next we use Fig. 5 to find grams. Grams = moles \times \text{g/mole} = 7.80 \text{ mole} \times 51.9961 \text{ g/mole} = 3163 \text{ g.}
Molarity, moles, and liters

Molarity (M) = moles/liter (mol/L or mole x L⁻¹). The liter is quite big and in the laboratory, liquid volume measurements are often carried out in milliliters (mL). We must be able to easily convert mL to liters. 1,000 mL = 1 L. To convert from mL to liters divide by 1,000.

Examples

1. A solution of 36.1 g NaCl is dissolved in sufficient water to give a total volume of 525 mL. The molar mass of NaCl is 58.44 g/mol. How do we get 58.44 g/mol? What is the molarity of the solution?

Solution: Molarity = moles/liter. We need to find the number of moles using Fig. 5.

Moles = 36.1 g / 58.44 gmole⁻¹ = 0.76 mol NaCl.

We convert ml to L. 525 mL = 0.525 L

Molarity = 0.76 mol/ 0.525 L = 1.28 mole/L or 1.28 M.

2. How many moles are in 250 mL of 0.023 M of NaOH solution?

Solution: We are given volume and molarity (M). From Fig. 6, we see that we can get moles by multiplying moles/L with L. We need to convert 250 mL to liters. 250 mL = 0.250 L, ¼ L.

As a reminder, moles/liter can be written as moles L⁻¹.

Moles = 0.023 moles L⁻¹ x 0.250 L = 0.0060 moles. The number of grams of NaOH needed to prepare the solution can be calculated by suing Figure 5. The molar mass of NaOH is 39.997 g/mol. Therefore amount in grams will be 39.997 g/mole x 0.0060 moles = 0.24 g.
Wavelength and frequency

Wavelength (λ), frequency (ν), and the speed of light (c) = 3.00 x 10^8 ms⁻¹ in a vacuum. In this particular case we have two variables and a constant, and we can still employ the same triangle method to find either wavelength when frequency is given or we can solve for frequency if we know the wavelength.

The speed of light c = wavelength x frequency; c = λν. Fig. 7 shows the relationship between variables and Fig. 8 shows the relationship between the corresponding units.

Examples

1. A microwave oven uses radiation with a frequency of 2.5 x 10⁹ /s. What is the wavelength of that radiation? Note that 2.5 x 10⁹/s can be written as 2.5 x 10⁹s⁻¹. Also remember that 1 hertz = 1 s⁻¹.

   Solution: Wavelength (m) = ms⁻¹ + s⁻¹

   Wavelength (m) = 3.00 x 10⁸ ms⁻¹ + 2.5 x 10⁹ s⁻¹ = 0.012 m = 12 cm

2. Ham radio operators often broadcast on the 6-meter band. What is the frequency of this electromagnetic radiation in MHz? 1 hertz = 1s⁻¹; 1MHz = 10⁶ Hz

   Frequency (s⁻¹) = ms⁻¹/m = ms⁻¹/m = s⁻¹(Hz)

   Frequency = 3.00 x 10⁸ ms⁻¹/6 m = 50 MHz.
The ideal gas equation

Even non-major students can use the following modified triangle to solve simple problems involving the ideal gas equation.

Example

Sulfur hexafluoride (SF₆) is an odorless, colorless, very unreactive gas. Calculate the pressure (in atm) exerted by 1.52 moles of the gas in a steel vessel of volume 2.72 L at 65.4°C.

Number of moles = 1.52; R = 0.0821 L.atm/K.mol; T = (65.4 + 273) K = 338.4 K; V = 2.72 L.

Using the triangle, Fig. 9,

\[ P = \frac{nRT}{V} = \frac{(1.52 \text{ mol})(0.0821 \text{ L.atm/K.mol})(65.4 + 273) \text{ K}}{2.72 \text{ L}} = 15.5 \text{ atm} \]

PRELIMINARY FINDINGS

Students’ comments about the use of triangles to solve simple problems

When I asked whether the use of triangles to solve problems was useful, the following representative responses were received. The total number of respondents was sixty two students.

- “Yes, I memorized all the triangles for this final and it was very helpful.”
- “No, I prefer to just use the formulas.”
• “Yes, the triangles were helpful. In high school, I could never remember how to do the mole ratios, but the triangles definitely helped.”

• “The triangles were extremely helpful because they are easy to use. You should print out an entire sheet with them on it, and let students use them on the test.”

• “Yes very! Gave visual representation to variables, plus, made going from one variable to another very easy.”

• “Yes, I liked the idea since it made it so easy to remember how variables were connected in different equations.”

• “Yes they were. They gave a simpler way to solve problems.”

• “Yes, they simplified the equations and were very easy to remember.”

• “Yes, it was easy to see how to get the unknown by looking at what made what in different sections.”

• “Yes, it was an easy way to remember how to relate the unknown to the two other things that were given.”

• “Yes, the triangles were very helpful in remembering how to convert from grams to moles as well as other equations (Density = mass/volume).”

• “I did not think they were helpful to me, because in math I was taught another way to do algebra. But my friends liked using triangles.”

• “Yes, I used the triangles to find density, molarity, and to convert moles to grams.”

• “I thought a few of the triangles were helpful, but if you understood the concept the triangles weren’t helpful or necessary. I found it easier to learn the concept rather than memorizing the order of things in the triangle.”
“Yes, they helped in remembering whether or not to multiply or divide, but were confusing at first.”

“I thought the triangles were very helpful. I’m a visual learner and I like to see things to ensure that I’m right and not count on my memory.”

“No. I was more confused using a triangle than when I was setting up a problem in a more algebra form. Stoichiometry was a lot easier for me to follow my work and double check it.”

“Yes, I loved it because I did not have to memorize three different equations for frequency, wavelength, and the speed of light. Learning the stupid symbols was hard enough.”

CONCLUSION

The triangle method to transform three variable equations, for example, the one that involves density, mass and volume; and those that involve two variables and a constant, for example, speed of light, wavelength and frequency were found to be useful for the majority of students. The weakest students were also able to draw triangles and use them to solve problems related to topics covered above. As long as students were able to rewrite an equation involving three variables in such a way that one variable is a product of the other two variables, which usually required simple cross multiplication, they found it easy to solve problems for an unknown variable when the other two variables were provided.

REFERENCES
SYSTEMIC APPROACH TO TEACHING AND LEARNING CHEMISTRY (SATLC) IN EGYPT (1998-2011)

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ABSTRACT
The rapid changes and increased complexity of today’s world present new global challenges on our education systems. The SATL contribution to education reform was dictated by the globalization of most human activities; the future of science education must reflect a flexibility to adapt to rapidly changing global needs. Fahmy and Lagowski since (1998) have designed, implemented, and evaluated the systemic approach to teaching and learning chemistry. Our aims have always been helping teachers to teach and students to learn more effectively by using SATLC. [AJCE, 2(2), February 2012]
INTRODUCTION

By "systemic" we mean an arrangement of concepts or issues through interacting systems in which all relationships between concepts and issues are made clear, up front, to the learner.

SATL is a new way of teaching and learning, based on the idea that nowadays anything is related to everything globally. Students shouldn't learn isolated facts (by heart), but connect concepts and facts in a logical context.

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 the future citizens of a world that is becoming increasingly globalized. We have conducted numerous experiments in which we attempted to establish the effectiveness of SATL methods not only in chemistry, but also in other basic sciences, medicinal sciences, engineering sciences, and Agriculture sciences. In chemistry, we have conducted a series of successful SATL-oriented experiments, at secondary and tertiary levels of education in Egypt.

WHY SYSTEMIC APPROACH

It verifies the major goals of educational system and proceeds towards systemic thinking and continuous growth of knowledge that is referred to as quality of education.

It represents a theme and method of teaching and learning beside its way of life that can be utilized in the management of various sides and activities of a normal citizen in all the scientific, and technological aspects.
The challenges that face the world today such as terrorism, environmental pollution...etc. that requires preparation of human calibers to be able to systemic and creative thinking that stops such phenomena for the sake of a better world for all.

- **Challenges that face the individuals in their home nations compared to what happens in the world such as:**

  - Mechanization of many local and international activities that require higher skills.
  
  - Procuring of many institutions and companies on the ISO (Total Quality Certificate).
  
  - Application of high tech. locally and internationally which requires a revision of many programs for preparing and training in order to cope with such technologies.

- **Theoretical bases on which the systemic approach stands on:**

  SATL stands on the wholistic vision for phenomena where linking different facts and concepts take place into a dynamic systemic network. This reflects the relationships which settles them into the cognitive construction of the learner and enables him to use it by a systemic way in different situations.

  It also helps learner to deduce new relations that enrich the operation of teaching and learning from its cognitive, psychomotor and emotional sides. SATL was based on the systems analysis and theory of constructivism. The following diagram illustrates the criteria, and products of learning by SATL.
☐ Application of SATL:

SATL was applied in the fields of Basic, Environmental, Agricultural, Engineering, Medicinal, and Linguistics...Sciences, in secondary and tertiary Education.

The statistical analysis of student achievement results shows that the students engaged with SATL materials and taught by teachers trained in systemics achieve at significantly higher levels than those taught by the standard linear methods.

☐ In Chemistry (SATLC):

➢ University level: There are four courses (SATL-Aliphatic Chemistry, SATL-Aromatic Chemistry, SATL-Heterocyclic Chemistry), and Green chemistry in lab experiments, for
Faculty of Science-students. These courses were successfully experimented, and applied now in different Egyptian Universities.

- **Pre-University level**: General chemistry course was prepared and tested.
  e.g.: systemic periodic table, systemic chemical bonding,

- **Systemic Objective Tests (SOT)**: were produced and experimented successfully in Egypt, e.g. systemic multiple choice Questions (SMCQs), Systemic True False Questions (STFQs), and Systemic Matching Questions (SMQ, s) in Chemistry.

- **Recently for IYC 2011**: we Use SATLC & Multiple intelligences [MI] in designing outdoor activities in Chemistry for tertiary level "Chemistry Gets Easier Initiative, CGEI".

- **Postgraduate Studies on SATL**: About 50 PhD and Maser students work on SATL in Egyptian and Arab universities; about 30 of them got their degrees.

- **Workshops and Conferences on SATLC**:
  - Two international workshops on SATLC were organized:
    One satellite to the third Arab Conference on SATL, Cairo, April, 2003, the other was in the 18th ICCE, Istanbul, and Aug. (2004).
    -10-Days Workshop on SATLC [PS-SATLC] was held at Karachi University, Pakistan (19-29, Nov.2008).

- **Conferences & Symposia and Seminars on SATLC**:
  - Six Arab conferences on (SATL) were held annually at Cairo, (2001-2006).
  - Two Jordanian-Egyptian conferences were held annually at Jordan (2005, 2006).
  - One symposium on (SATL) satellite to 20th ICCE was held at Mauritius (Aug.2009).
- About 60 seminars were organized on systemic Approach, and Systemic Assessment in Egypt, Libya, Syria, Algeria, Jordan and Pakistan.

- **Training Programs on SATL:** More than 50,000 teachers were trained in Egypt on SATL part of them are chemistry teachers.

- **See Also**
The African Journal of Chemical Education (AJCE) is a biannual online journal of the Federation of African Societies of Chemistry (FASC). The primary focus of the content of AJCE is chemistry education in Africa. It, however, addresses chemistry education issues from any part of the world that have relevance for Africa. The type of contents may include, but not limited to, the following:

**RESEARCH PAPERS** reporting the results of original research. It is a peer-reviewed submission that deals with chemistry education at any level (primary, secondary, undergraduate, and postgraduate) and can address a specific content area, describe a new pedagogy or teaching method, or provide results from an innovation or from a formal research project.

**SHORT NOTES** containing the results of a limited investigation or a shorter submission, generally containing updates or extensions of a topic that has already been published.

**REVIEWS** presenting a thorough documentation of subjects of current interest in chemical education.

**LABORATORY EXPERIMENTS AND DEMONSTRATIONS** describing a novel experiment/demonstration, including instructions for students and the instructor and information about safety and hazards.

**SCIENTIFIC THEORIES** describing the scientific, historical and philosophical foundations of theories and their implications to chemical education.

**ACTIVITIES** describing a hands-on activity that can be done in the classroom or laboratory and/or as a take home project.

**INDIGENOUS KNOWLEDGE AND CHEMISTRY IN AFRICA** as a special feature that addresses the relationship between indigenous knowledge and chemistry in Africa. It could be in the form of an article, a note, an activity, commentary, etc.

**LETTER TO THE EDITOR:** A reader response to an editorial, research report or article that had been published previously. The short piece should contribute to or elicit discussion on the subject without overstepping professional courtesy.

All manuscripts must be written in English and be preferably organized under the following headings: a) **TITLE**, Author(s), Address(es), and **ABSTRACT** in the first page, b) **INTRODUCTION** reviewing literature related to the theme of the manuscript, stating the problem and purpose of the study, c) **METHODOLOGY/EXPERIMENTAL** including the design and procedures of the study, instruments used and issues related to the reliability and/or validity of the instruments, when applicable, d) **RESULTS AND DISCUSSION**, e) **REFERENCES** in which reference numbers appear in the text sequentially in brackets, each reference be given a separate reference number, *et al* and other notations like *Ibid* are avoided, and finally f) **ACKNOWLEDGEMENTS**.

When submitting a manuscript, please indicate where your manuscript best fits from the above list of categories of content type. All enquiries and manuscripts should be addressed to the Editor-in-Chief: email eic@faschem.org, PO Box 2305, Addis Ababa, Ethiopia.