DIAGNOSING THE DIAGNOSTICS: MISCONCEPTIONS OF TWELFTH GRADE STUDENTS ON SELECTED CHEMISTRY CONCEPTS IN TWO PREPARATORY SCHOOLS IN EASTERN ETHIOPIA

Abayneh Lemma,Ethiopia
misabbay@gmail.com

ABSTARCT

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 pre-requisite 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).

Parameter	**Factors that cause the break down**	**Examples**
Oxidation number	i. Homonuclear element-element bonds are present	i. Me_4C:C is tetravalent but has an oxidation number of zero
	ii. Two ligands attached to the atom of interest have opposite charges (e.g., Cl^- and H^-)	ii. CH_2Cl_2: C is tetra but has an oxidation number of zero
	iii. The molecule is charged and the ligand is dissociated as a cation (e.g., H^+)	iii. $[NH_4]$ - : N is pentavalent but has an oxidation number of -3.
No. of bonds	The atom in question bears a formal charge (valence = no. of bonds + formal charge)	$[BH_4]$- ; B is tetravalent but has four bonds.
Coordination number	i. A multiple bond is present	i. H_2 C=CH_2: C is tetra valent but 3-coordinate HC=CH: C is tetravalent but 2-coordinate.
	ii. A dative ligand is present	ii. H_3NBH_3: B is trivalent but 4-coordinate.

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 DISCUSION

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

Item	Categories	frequencies
1	**M V**alence, 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.	12
	* 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.	--
2	F ormal charge of a given element is constant in all compounds and radicals containing the element	28
	*Formal charge and oxidation number are similar in that they are	

	concerned with charges assigned to a given element, though the conditions, in which the charges are assigned and their magnitudes are different.	16
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.	6
	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.	18
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.	28
	*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.	7
4.2	**M** In every compounds of nitrogen, its valence and oxidation state are respectively 5 and -5.	26
	*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.	8
5	*The oxidation number of an element in its neutral compounds (ex. N in NH_3) is equal to its oxidation number in radicals (ex. N in NH_4^+)	24
	M The oxidation number of an element in its neutral compounds (ex. N in NH_3) is not equal to its oxidation number in radicals (ex. N in NH_4^+)	18
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.	12
	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.	19
7	**M** The formal charge of carbon (in its compounds) is equal to its respective oxidation state.	2
	*The formal charge of carbon (in its compounds) could not always be equal to its respective oxidation state.	46
8	The values of formal charge of an element in its neutral compounds (ex, N in NH_3) and radicals (ex, N in NH_4^+) are not equal (which are respectively 0 and +1).	12
	The values of formal charge of an element in radicals (ex, N in NH_4^+) and compounds containing the radicals (ex, N in NH_4Cl) are equal, which is +1.	28

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.

		One-tier test	Two-tier test	Three-tier test
Reliability	$\alpha_{(Score)}^{*}$	0.61	0.65	0.78
	$\alpha_{(misconception)}^{+}$	0.62	0.70	0.82
Validity	Construct	Student Score-2 Vs Confidence Level		0.45
	Content	Mean Proportion of False Negative Mean Proportion of False Positive		6% 12%
Item analysis	D′	0.28	0.29	0.36
	$P^{£}$	0.38	0.32	0.33

* Reliability coefficient calculated based on students' scores
+ Reliability coefficient calculated based on students' misconceptions
′ Average item discrimination index
£ 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 4: Proportion of students' scores in each item and tier

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

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

Item	**One-tier test**		**Two-tier test**		**Three-tier test**
	Misc-1 (%)	% of overestimation	Misc-2 (%)	% of overestimation	
1	35	6	31	2	29
2	37	8	33	4	29
3	36	7	33	4	29
4	41	11	35	5	30
5	53	17	48	12	36
6	47	13	41	7	34
7	32	10	32	10	22
8	47	14	42	9	33
9	34	14	28	8	20
10	38	9	34	5	23
11	38	15	33	10	23
12	42	9	40	7	33
average	40	12	36	8	28

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.

		One-tier test	Two-tier test	Three-tier test
Reliability	$\alpha_{(Score)}$ †	0.61	0.65	0.78
	$\alpha_{(misconception)}$ +	0.66	0.76	0.87
Validity	Construct	Student Score-2 Vs Confidence Level		0.45
	Content	Mean Proportion of False Negative Mean Proportion of False Positive		6% 12%
Item analysis	D′	0.28	0.32	0.36
	P£	0.41	0.35	0.33

* 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, α, 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 RECOMMENDTIONS

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_4Cl) 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

1. Temechegn, E. (2002). Students' alternative conception: Challenging the challenge, solutions: *A biannual news letter of the Chemical society of Ethiopia, Vol. 10, No. 1 & 2:11-14.*
2. Yasin, K. (2004). Diagnosis of eleventh grade Misconception about Geometric Optics by a Three-tier test. M. Sc. Thesis report. Middle East Technical University.
3. 3. Smith, W.D. (2005). Valence, covalence, hypervalency, oxidation state and coordination number. *Journal of chemical education, 72(4): 27-32.*
4. 4. Perkins, G. (2006). Valence, oxidation state, and formal charge: Three related, but fundamentally different concepts. *Journal of chemical education 69(3) 191-196.*
5. Al-Rubayea, A. A. M. (1996). An analysis of Saudi Arabian high school students' misconceptions about physics concepts in Yasin, K. (2004), a M.Sc. dissertation thesis report. M. Sc. Thesis report, Middle East Technical University.
6. Marx, J. D. (1988). Creation of a diagnostic exam for introductory, undergraduate electricity and Magnetism. Rensselaer Polytechnic Institute, Troy, New York. Dissertation Abstracts International (University Microfilms No.9908686). Last accessed date September 2008.
7. Fraenkel, J. R. and N. E. Wallen, (1996). How to design and evaluate research in education. (3rd ed.). New York: McGraw-Hill. Downloaded PDF, last accessed Sept, 2001.
8. Thorndike, R. M., (1997*). Measurement and Evaluation in Psychology and Education,* 6th edition. Macmillan Publishing Company, LB131M433.
9. Rollnick, M. and P. P Mahooana, (1999). A quick and effective way of diagnosing student Difficulties: two tier from simple multiple choice questions in Yasin, K. (2005). Diagnosis of eleventh grade Misconception about Geometric Optics by a Three-tier test. Middle East Technical University
10. Griffard, P. B. and Wandersee, J. H. (2002). The Three-Tier Instrument: Its difficulty. *International Journal of Science Education 11(6) 331-357.*
11. Levy, T., A., Hofstein, R. Mamlok, and Z Bar-dov, (2004). Can final examination amplify Students' misconception in Chemistry? *Journal of Chemical education: Research and Practice Report, 71(4) 97-103.*

AKNOWLEDGEMENT

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.