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# Understanding the Concepts of Symbols, Formulas, Valencies and Chemical Equations by Pakistani Teachers and Students

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**KEY WORDS**

Science teachers, students, chemistry textbook grade IX, Pakistan.

**ABSTRACT**

Symbols and valencies are essential for writing formulas, which in turn are used to write chemical equations. If the students have not grasped the concept of writing formulas and equations then further learning of chemistry becomes difficult. This article is based on a research study to investigate the understanding for symbols, formulas, valencies and chemical equations of Secondary School Teachers (SSTs) science and class IX students of Chakwal District. Convenient sample of 17 science teachers and 281 students was selected. The sample of the science teachers and students was representative of the four tehsils of district Chakwal. Data were collected by means of a test consistent upon four parts pertaining to symbols, formulas, valencies and chemical equations. The test carried 80 marks, 10 marks for Part A, 30 marks for Part B, 20 marks for Part C and 20 marks for Part D. Teachers and students were given the same set of test. Data were

analyzed to find out the strong and the weak Parts by finding out the percentages of the four Parts. The performance of the teachers in all four parts remained better as compared to the students. The strongest part of the teachers was Part D i.e. balancing the equations and the weakest part was of Part B i.e. writing the valencies. The strong and the weak areas of the students were different as compared to the teachers, their strong part was Part A pertaining to symbols and the weak part was Part C pertaining to writing equations.

## Introduction

Chemistry is a major subject of science. Laureano, Espinosa and Avilla (2015) stated that a weak chemistry base at the secondary school level will result in low future achievement in this subject. The knowledge of Chemistry is helpful in solving of daily life problems.

Laugier and Dumon (2004) conducted a test on French lower secondary students and found that pupils do not seem to have mastered the language of chemistry. The majority had no understanding of the basic rules of writing symbols and chemical formulas. Most of the pupils associated the name of an element or molecule to its chemical symbol; only 40% can produce the chemical formula of a compound with a clear understanding of its composition and fewer than 20% succeeded in the reverse operation.

Arem et. al (2012) also advocated to learn and practice the terminology of chemistry in the form of chemical symbols. Learn to name the chemical substance when given the symbol or chemical formulas and learn to write the symbols or the formulas of a substance when given the chemical name. In everyday life when coming across the names of chemical compounds on products at groceries and pharmacies, students should try to recognize the common and the chemical name e.g. vinegar for acetic acid, and methylated spirit for ethanol and bleach for sodium hypochlorite. Writing formulas is only possible when the students have mastered the learning of symbols and valencies. Afterwards the concept of chemical equations and balancing of chemical equations is introduced.

Taber (2002) mentioned that impediments can occur at two levels: firstly, where students fail to make sense of the teaching because of prior knowledge gaps and they fail to assimilate their new information into their existing framework. Secondly, where a student has wrong conception either on his own or due to inappropriate teaching.

Yarroch (1985) conducted research on the students' understanding of chemical equation balancing. Fourteen American high school chemistry students from two different schools were interviewed in depth on how they balanced simple chemical equations; all students were able to successfully balance the four equations presented to them. However, seven of the twelve

students were not able to write the notation of the balanced equation. It was further noted that these same students possessed very poor understanding of the concept of chemical subscript and were willing to violate the balancing rule, which states that subscripts are not to be changed while balancing equations.

Johnstone (2006) mentioned in the early 1960's, Scotland adopted new curricula in chemistry for secondary schools (ages 12-18 Years). Samples from two schools were selected. Each student who had studied the new curriculum was given a list of all the topics and sub topics in chemistry curriculum and asked to categorize each of them into one of the four groups.

a) I understand this easily
b) I had some difficulty but I now understand it
c) I have never understood this and will need to be taught it again
d) I have never been taught this

The most chosen was the category 'c' by both the universities against the topics, writing formulas, equations and doing calculations from them.

Howe (1971) working on formulae and equations at school level, tried to work backwards through the operations underlying the writing of 'simple' inorganic formulae. His backward operations were the: a) elements in a given compound, b) symbols for these elements, c) charges on the ions of these elements, and d) formulae of the compound. In most of the 50% of the responses for familiar binary compounds, pupils made mistakes in the first three steps and yet got the formula correct. Interview revealed that pupils did not try to construct formulae from first principles but simply memorized the ones most commonly used.

Meyer and Land (2006) termed some of the ideas as core to understanding the subject and they termed them as threshold ideas. Failure to understand threshold concepts leaves the learner lacking in understanding. Teaching staff of Nottingham Trent University and secondary science teachers were asked to identify the students' difficulties with scientific concepts. It was intended to help identify those areas of the Post 16 curricula where conceptual difficulties are carried through into undergraduate study. 18 academic staff from a range of sciences listed valency, writing formulas and equations as difficult/troublesome concepts for their students amongst the concepts not well taught at school.

Khurshid (2011) mentioned in the study of Effectiveness of Expository and Inquiry Instruction on the Modification of Misconceptions in General Science at Elementary level conducted by the researcher revealed that the schools where no science teachers were available, the students were unable to write chemical formulae and chemical equations.

The chief examiner's report of the West African Examination Council (WAEC) cited in Onyenenue (2016) identified specific topics where students' achievement in Chemistry was low. These included writing of

chemical formulae and balancing of equations.

Yitbarek (2011) refers to chemical equation as a language of the chemistry. Once, these are introduced, it is assumed that the students will be able to understand these. But many difficulties lie in understanding and learning chemical equations. Chittelborough as cited in Jones (2008) mentioned the three levels of Chemistry macroscopic, particulate and symbolic representation. In macroscopic representation, use of five senses is made to perceive chemical phenomena such as change of colour, precipitation and heat etc. Phenomena where interaction of atoms, ions, electrons and molecules is involved is known as particulate representation and our senses are unable to perceive this phenomena. In symbolic representation, symbols, chemical equations and a large variety of graphic representations are used. The ability of the students to interpret from one representation to another is called representational competence. Why is it difficult to learn chemistry? Students find difficulties while moving from one level to another. Tasker and Dalton cited in Gilbert, Reiner and Nakhleh (1993) stated that students find it difficult in moving from the macroscopic to the particulate level. Kosma and Russell cited in Naah (2012) state that students find difficult the relationship between the levels.

In the Government of Pakistan, National Curriculum of General Science for Grade IV-VIII (2006), Ministry of Education Islamabad, the students of class VI are expected to recognize the symbols of some common elements. In Grade VII, the concept of valency is introduced after the structure of an atom and electronic configuration. After this, the students are expected to write chemical formulae. Concept of chemical equation and balancing is introduced in Grade VIII.

The chemical equations enable the students to think about the change-taking place at atomic and molecular level and it requires a large measure of abstraction. It should not be taken for granted that the students are able to achieve an intellectual process with no time lapse, which took centuries for the scientists to construct.

All these concepts of symbols, valency, chemical formulae and balancing of chemical equations are mentioned in a logical sequence in the National Curriculum. By the end of Grade VIII, the students are expected to describe the formulas, chemical equations, symbols and its relationship with molecules, atoms, and ions. In the first unit of Grade IX based on Government of Pakistan, National Curriculum for Chemistry (2006), the students are expected to learn the fundamentals of Chemistry. This unit has conceptual linkages to symbols, chemical formulas which the students have learnt in Grades VI - VIII. The students are expected to learn the concepts of symbols, valency, chemical formulae and balancing of chemical equations step by step in a logical sequence.

Keeping in view the importance of symbols, valances, formulas and chemical equations in the subject of chemistry; this research study was

carried out to investigate the understanding of the concepts of symbols, formulas, valencies and chemical equations by Pakistani science teachers and students.

## Key Terms in the Study

Terms central to this study are defined as follows:

**Symbols -** are the prerequisites for learning chemistry as the alphabets are for learning a language. Some chemical symbols do not relate to the names of the elements and are drawn from languages other than English e.g. symbol of Lead (Pb) and mercury (Hg) are taken from Latin language i.e. Plumbum and Hydrargyrum respectively.

**Valencies -**The valencies of elements and radicals tell us whether they have the ability to gain or lose electrons, which in turn determines the number of atoms or radicals it will combine with. This is from where the concept of formula starts. Na has the tendency to lose one electron so it has +1 valency ($Na^{+1}$), Cl has the tendency to gain one electron; its valency is –1, ($Cl^{-1}$). The $HSO_4$ radical has the tendency to gain one electron, its valency will be –1, ($HSO_4^{-1}$), $NH_4$radical tends to lose one electron, and its valency will be +1, ($NH_4^{+1}$). The ions and radicals which have the tendency to lose electron/s are the basic radicals e.g. $Na^{+1}$ and $NH_4^{+1}$. The ions and radicals having negative charge are acidic radicals e.g. $Cl^{-1}$ and $HSO_4^{-1}$.

**How to write the formula -** In order to write the formula of sodium chloride, the symbols of sodium and chloride are written along with their valencies $Na^{+1}Cl^{-1}$ . Now valencies of both the ions (Na and Cl) are cross multiplied. Both the ions have valency 1, so the formula will be NaCl. Another example is of aluminium chloride, the valencies of both the ions are written, $Al^{+3}Cl^{-1}$. The valency of both the ions is cross multiplied, $Al^{+3}\ Cl^{-1}$ and the formula of aluminium chloride will be $AlCl_3$. The ability to communicate the structure of a substance through writing its formula is a vital precursor for further studies. If students cannot write the formulae of substances then further work (e.g. on equations) is difficult.

**Chemical equations -** 'Chemical equations' mean the direction of change from reactants to products. After writing the formulas of reactants and the products, a concept of balancing the equations is introduced. Mulhallet et. al (2003) state that the students are expected to know that during a chemical reaction, the disappearance of reactants and formation of products correspond to the rearranging of atoms within new molecules.

A chemical change takes place by means of a chemical reaction and is symbolized by a chemical equation. At the first level of development, in a chemical equation, the number of elements in the reactants and products are conserved. At the second level of development, the number of atoms of elements is conserved. At the microscopic level during a chemical change electron/s of an atom's valence shell are involved either by covalent or ionic

bonding within molecules or in the form of ions as the case may be. The equation of a reaction represents as to what happens on the microscopic scale when molecules or atoms react with one another.

**Senior School Teachers (SSTs) Science** -Minimum qualifications of these teachers are Bachelor of Science (B.Sc) and Bachelor of Education (B.Ed).

## Objectives of the Study

The objectives of the study are to identify science teachers and Grade IX students' difficulty in teaching and learning chemistry in these four areas:

1. Encoding symbols to the general names of elements and decoding the symbols of elements.
2. Determining valencies of the elements and radicals.
3. Formulating the equations by encoding the symbolic formulae of the reactants and the products.
4. Balancing the equations.

## Methodology

This study used survey design and achievement test was used to examine teachers' and students understanding on symbols, formulas, valencies and chemical equations of SSTs of Science and class IX students of district Chakwal.

### Population

The enrolment of male and female students in class IX of science group in district Chakwal during the year 2011 was 10387 as recorded by the office of the District Education Office (SE) District Chakwal comprised the population of the study. The male and female SSTs of science working in public schools of district Chakwal comprised the population of the study.

### Sample

There were four tehsils in district Chakwal i.e. tehsil Chakwal, tehsil Talagang, Tehsil Kallar Kahar and Tehsil Choa Seyden Shah. The sample was representative of the four tehsils in the case of science teachers as well as the students. A sample of 281 students studying Chemistry was selected on convenient basis.

In district Chakwal, 46 CTSCs were made for the purpose of in-service teacher training by Directorate of Staff Development., Lahore. The number of CTSCs from tehsil Chakwal was 22, Talagang 18, Kallar Kahar 3 and Choa Seyden Shah 3.

Table 1
*School-wise sampling frame for the study*

| Sr.# | Name of Boys' Schools | Name of Girls' Schools | No. of Students | Tehsil |
|---|---|---|---|---|
| 1. | | GGHS No. 2 Chakwal | 07 | Chakwal |
| 2. | | GGHS No. 3 Chakwal | 07 | Chakwal |
| 3. | GHS Bheen | | 14 | Chakwal |
| 4. | GHS Chak Malook | | 14 | Chakwal |
| 5. | GHS Tamman | | 14 | Talagang |
| 6. | | GGHS Tamman | 14 | Talagang |
| 7. | | GGHSS Danda Shah Bilawal | 05 | Talagang |
| 8. | | GGHS Pichanand | 07 | Talagang |
| 9. | GHS Pichanand | | 22 | Talagang |
| 10. | GHS Chinji | | 26 | Talagang |
| 11. | GHS Multan Khurd | | 25 | Talagang |
| 12. | GHSS Kallar Kahar | | 30 | Kallar Kahar |
| 13. | | GGHS Kallar Kahar | 07 | Kallar Kahar |
| 14. | GHS Bochal Kalan | | 15 | Kallar Kahar |
| 15. | | GGHS Bisharat | 07 | Choa Seyden Shah |
| 16. | GHS Choa Seyden Shah | | 74 | Choa Seyden Shah |

N=281

## Instrumentation

For collection of data an achievement test was developed by the researchers. In order to ensure the validity and reliability, the test was piloted on a sample of 10 students of Government High School Choa Seyden Shah. The time given for the test was one hour. The test was validated by three experts prior to administering it in the field. The reliability of the final test was established at 0.98 Alpha.

The test contained four parts (A, B, C and D), all comprising 80 marks to be solved in one hour. Part A was related to symbols and elements. It was consistent upon 10 multiple choice test items. Each test item had four alternatives. In the five test items the subjects were expected to choose the correct symbols for the elements. In the rest of the five test items, the subjects were expected to choose the correct element for the provided symbol. Each test item carried one mark. The total marks for Part A were 10. Part B contained 30 test items. The subjects were expected to write down the symbol or formula (as the case may be) along with the valency. Each test item carried one mark. The total marks assigned to this part were 30. Part C was related to balancing the equation. There were 10 test items in it. Each test item carried 2 marks. The total marks assigned to Part C were 20. Part D was related to writing the equations for the provided reactants and products. There were 10 test items in it. Each test item carried two marks. The total

marks allocated for this portion were 20.

The data was collected in January – February 2011. The science teachers and the class IX students were administered the same test. Only one school was administered the test in one day. The following procedure was adopted for data collection.

i) In the first phase, the test was administered to the 14 male science teachers participating in science teachers training in Govt. High School No. 1 Chakwal and test was administered to the three girls' schools science teachers by personal visit to their respective school. In both the cases, data were collected by the principal researcher.

ii) In the second phase, the students were administered the test who were drawn from the same four tehsils of district Chakwal through convenience sampling. Data were collected by the principal researcher coinciding with the scheduled visits of the Cluster Training & Support Centres (CTSCs).

## Data Analysis and Discussion of Results

Data were analyzed by allocating one mark to each correct answer in part A and B of the test. Two marks were given for balancing the equation in Part C. Two marks were given for writing the correct formulae of the reactants and products of the chemical equation. The percentages of every part (A, B, C and D) were calculated.

Table 2 indicates the teacher-wise performance in the test.

Table 2

*Teachers' Performance in Different Parts (A, B, C, and D) of the Test*

| Sr.# | Name of School | Part A (10 Marks) | Part B (30 Marks) | Part C (20 Marks) | Part D (20 Marks) |
|---|---|---|---|---|---|
| 1 | GGHS ChakMalook | 9 | 19 | 20 | 20 |
| 2 | GGHS No.2 Chakwal | 9 | 13 | 18 | 20 |
| 3 | GGHS No.3 Chakwal | 9 | 7 | 14 | 17 |
| 4 | GGHS Pichnand | 7 | 7 | 17 | 19 |
| 5 | GHS Bheen | 8 | 0 | 15 | 19 |
| 6 | GHS Chinji | 8 | 11 | 20 | 20 |
| 7 | GHS Chinji | 8 | 9 | 7 | 7 |
| 8 | GHS ChoaSeyden Shah | 10 | 10 | 18 | 20 |
| 9 | GHS ChoaSeyden Shah | 10 | 3 | 20 | 20 |
| 10 | GHS Kallar Kahar | 8 | 22 | 18 | 20 |
| 11 | GHS Maingan | 9 | 2 | 17 | 16 |
| 12 | GHS Mangwal | 8 | 14 | 14 | 11 |
| 13 | GHS Multan Khurd | 9 | 10 | 20 | 18 |
| 14 | GHS Mureed | 10 | 12 | 19 | 18 |
| 15 | GHS Pichnand | 8 | 0 | 20 | 19 |
| 16 | GHSS KallarKahar | 10 | 26 | 20 | 20 |
| 17 | GHSS Tamman | 8 | 20 | 16 | 20 |
| | Percentage | 87% | 36% | 86% | 89% |

The test showed that the science teachers performed strongly (89%) in providing the chemical names of reactants and products. The weakest part was (36%), writing valencies of symbols and formulas.

Table 3
*Students' Performance in Different Parts (A, B, C, and D) of the Test*

| Sr.# | Name of School | Part A (10 Marks) | Part B (30 Marks) | Part C (20 Marks) | Part D (20 Marks) |
|---|---|---|---|---|---|
| 1 | GGHS Bisharat | 25 | 31 | 11 | 31 |
| 2 | GGHS Danda Shah Biliwal | 15 | 13 | 4 | 23 |
| 3 | GGHS KallarKahar | 38 | 58 | 31 | 48 |
| 4 | GGHS No. 3 Chakwal | 20 | 22 | 4 | 26 |
| 5 | GGHS Pichnand | 16 | 12 | 2 | 10 |
| 6 | GGHS Tamman | 29 | 30 | 0 | 29 |
| 7 | GHS Bheen | 47 | 30 | 47 | 31 |
| 8 | GHS BochalKalan | 59 | 34 | 0 | 10 |
| 9 | GHS ChakMalook | 52 | 52 | 6 | 39 |
| 10 | GHS Chinji | 89 | 54 | 11 | 37 |
| 11 | GHS Choa Seyden Shah | 613 | 79 | 7 | 52 |
| 12 | GHS Multan Khurd | 56 | 35 | 0 | 17 |
| 13 | GHS No. 2 Chakwal | 30 | 37 | 34 | 56 |
| 14 | GHS Pichnand | 47 | 22 | 0 | 11 |
| 15 | GHS Tamman | 45 | 38 | 0 | 9 |
| 16 | GHSS KallarKahar | 52 | 27 | 20 | 92 |
| | Percentage | 43.8% | 6.8% | 3.15% | 9.55% |

The strongest area (43%) of the students was translatory task i.e. to choose the element for the provided symbol or vice versa. The weakest Part was (3.15%) related to balancing the equations. In Part B (6.8%) the students were expected to write down the symbol or formula (as the case may be) along with the valency and Part D (9.55%) was related to writing the equations for the provided reactants and products. In Part B & Part D, the students' achievement remained low.

Table 4
*Percentage of Encoding and Decoding*

| Teachers/ Students | Encoding ($A_1$) | Decoding ($A_2$) |
|---|---|---|
| Teachers | 88.48% | 85.45% |
| Students | 34.87% | 25.33% |

Both the teachers and the students showed higher percentage in encoding the symbols.

Table 5
*Test Performance of Students and Teachers*

| Percentage of Students/ Teachers | Symbols (Part A) | Valencies (Part B) | Writing equations (Part C) | Balancing the equations (Part D) |
|---|---|---|---|---|
| Percentage of Teachers | 87%<br>2 | 36%<br>4 | 86%<br>3 | 89%<br>1 |
| Percentage of Students | 43.8%<br>1 | 6.8%<br>3 | 3.15%<br>4 | 9.55%<br>2 |

The performance of the teachers and the students regarding the different Parts of the test (A, B, C, D) was different as is manifested by the ranking in each cell. The best performance of the teachers was in Part D while that of the students was in Part A. The teachers' performance ranked the least in Part B while the students showed the least performance in Part C of the test.

The overall summary of the results can be seen as;

1. Percentage of teachers regarding encoding and decoding (Part $A_1$& $A_2$) was 88.48% and 85.45% respectively. Percentage of students regarding encoding and decoding was 34.87% and 25.33% respectively. (Objective 1)
2. Percentage regarding writing valancies (Part B) of the teachers and students was 36% and 6.8% respectively. (Objective 2)
3. Percentage regarding writing chemical equation (Part C) of teachers and students was 86% and 31.5% respectively. (Objective 3)
4. Percentage regarding balancing the chemical equations (Part D) of teachers and students was 89% and 9.55% respectively. (Objective 4)

## Conclusions

The teachers' performance was the highest in part D. This part of the test was related to writing the chemical equations in balanced form by writing the formulae of the provided reactants and products. The teachers showed the lowest performance in part B. This part of the test was related to writing the symbols and formulae of the elements and radicals along with valencies. The teachers wrote the formulas through experience without laying much emphasis to the electronic configuration of an atom.

The students' performance was the highest in part A. In this Part, the subjects were expected to select the symbols of the elements (encoding) or the elements of the symbols (decoding) as the case may be. The students were good at encoding ($A_1$) and decoding ($A_2$) of the elements but they were unable to write the chemical formulas. Writing symbols from general names of elements was related to rote learning only. Writing formulas involved the use of valencies which in turn made the use of the knowledge of electronic configuration of atoms about which the student's knowledge seemed poor.

Both the teachers and the students were better in encoding rather than decoding.

The students' performance was the lowest in part C. This part of the test was related to balancing the equations. Those students who were unable to write balanced equations seemed unaware of the concept of "conservation of the mass" which was applied in balancing of the equations. The students could not apply the concept that the total number of the atoms remained the same on the left hand side and the right hand side of the reactants and products respectively. This showed that the majority of the students could not relate the symbols and the formulae of the elements and compounds respectively to the number of atoms taking Part in the reaction.

A research study conducted by Khurshid (2009) on Children's Misconceptions about Changes, Acids and Laboratory Preparation of $CO_2$ also manifested that the lowest percentage of correct answers (0%) of elementary students was regarding writing and balancing the equations. The teachers' performance was much higher as compared to the students' performance in all the four Parts (A, B, C, D) of the test.

## Recommendations

1. At elementary level, in most of the schools, General Science is not taught by qualified science teachers (i.e. SSTs for science), the students' knowledge about the symbols, valencies, formulas and balancing the equations remain poor as was investigated in the Ph.D dissertation of the principal researcher. It is suggested that in-service teacher training must be provided to the elementary teachers about symbols, valencies, formulas and balancing the equations so that base of the students is set for these basic concepts at elementary level.
2. Researches should be conducted regarding the understanding of other concepts of Grade IX chemistry.
3. The concepts of chemistry which the students find difficult to understand must be identified and instructional strategies may be designed to address these difficulties.

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