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ABSTRACT

The purpose of this study was to assess the impact of eighteen 11th grade high school chemistry students' prior mathematical knowledge on their understanding of certain chemical concepts (symbol, formula, and equation). It also investigated students' ideas about the meaning of plus sign, reaction sign, and the relationships between subscript, and coefficient. A combination of quantitative and qualitative methods were employed in a two-stage approach involving a preliminary study and a main study over one academic school year. The cooperating high school chemistry teacher was an active participant consultant throughout the research process. The findings indicated that about one-third of the interviewed students held common prescientific conceptions and the remainder of the students held unique concepts. The identified prescientific conceptions were common and prevalent among the students regardless of achievement level, sex, interest, age, and prior knowledge, and seemed to have different causes/sources. Based on these findings, recommendations are made and implications are suggested for high school chemistry teachers, curriculum developers, and chemistry education researchers. (Author)

Investigation of High School Chemistry Students' Concepts of Chemical Symbol, Formula, and Equation: Students' Prescientific Conceptions

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INVESTIGATION OF HIGH SCHOOL CHEMISTRY STUDENTS' CONCEPTS OF CHEMICAL SYMBOL, FORMULA, AND EQUATION: STUDENTS' PRESCIENTIFIC CONCEPTIONS

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ABSTRACT

The purpose of this study was to assess the impact of 11th grade high school chemistry students' prior mathematical knowledge on their understanding of certain chemical concepts(symbol, formula, and equation). It also investigated students' ideas about the meaning of plus sign, reaction sign, and the relationships between subscript, and coefficient. A combination of quantitative and qualitative methods were employed in a two-stage approach involving a preliminary study and a main study over one academic school year. The cooperating high school chemistry teacher was an active participant consultant throughout the research process. The findings of this first stage were used to sharpen the focus of the main study. Content analysis using preestablished criteria as well as two groups of experts were used in the data analysis process for the purposes of validity and reliability.The findings indicated that about one-third of the interviewed students held common prescientific conceptions and the remainder of the students held unique concepts. The identified prescientific conceptions were common and prevalent among the students regardless of achievement level, sex, interest, age, and prior knowledge, and seemed to have different causes/sources. Based on these findings, recommendations are made and implications are suggested for high school chemistry teachers, curriculum developers, and chemistry education researchers.

Science educators and researchers have been investigating students' prescientific conceptions(i.e., misconceptions) about natural and technological phenomena for some 100 years (Browning & Lehman, 1988). There was a wide interest in prescientific conceptions research in the first half of this century, then it declined in the 1960s and 1970s (Trembath, 1983; Trembath Barufaldi, 1981). The existence of students' prescientific conceptions in children's thinking was documented as long ago as 1920 by Piaget (Hewson, 1985), but science educators and researchers have seriously considered this issue in only the last decade (Browning & Lehman, 1988). Currently, it is an extending field, booming, flourishing, developing, and increasingly recognized (Anderson, 1986; Duit, 1990; Reif, 1990). Also, it is one of the most prominent areas of concern in science education which has exhibited dramatic and worldwide growth (Bliss, 1988; Duit, 1989; Gunstone, White, & Fensham, 1988); Hashweh, 1986; Preece, 1983).

Most of the work that has been done on students' prescientific conceptions in chemistry was done in the 1980s (Nakhleh, 1992) and has been increased, although to a lesser extent than in physics and biology (Garnett & Treagust, 1992; Nakhleh, 1992).

The term " prescientific conception" is not the only term used to describe students' ideas which are inconsistent with scientific views; there are about 100 terms have been used in science education research. These terms do not have the same meaning and indicating different perspectives among science educators and researchers. The problem of selecting the most meaningful and useful term remains unresolved (Albimola, 1988). Gunstone (1989) argued against the use of a single term while Albimola (1988) argued for the use of a single term. And the debate goes on. For more information about the terminology problem and a list of the terms, see AL-Kunifed (1993). We used the term "prescientific conception" in terms of the following points: (a) it is more comprehensive, (b) it does not carry a negative connotation, (c) it can apply to adults as well as children and (d) it is specific to science (Good, 1991).

There is almost complete consensus among science educators and researchers that American high school students and teachers consider chemistry as one of the most difficult subjects in the high school curriculum. This difficulty has been attributed to various factors: (1) the presence of students' and teachers' prescientific conceptions (Anderson & Smith, 1983; Ben-Zui, Eylon, & Silberstein, 1982, 1987; Bodner, 1986; Duit, 1990; Herron, 1990; Nakhleh, 1992; and Vosniadou, 1991), (2) the lack of integrating new concepts within existing concepts (Farragher & Szabo, 1986;

Kleinman, Griffin, & Kener 1987; McDermott 1988; and West & Fensham 1979). (3) students lack the basic concepts they need to connect chemical and mathematical information meaningfully and rely on algorithmic methods only (Gable & Samuel, 1986; Gable & Sherwood, 1984; Gabel, Sherwood, & Enochs, 1984; Herron, 1990; Kolb, 1978; and Kouba, 1989), (4) the conflict between students' prior knowledge and chemical knowledge (Claxton, 1988; Herron, 1990; Osborne, Bell, & Gilbert, 1983; and West & Fensham, 1979) , (5) students use mathematical laws in a manner which contradicts their previous experiences in mathematical instruction, students are unable to apply the mathematical reasoning to chemical situations, and often students do not recognize chemical terms and are unable to apply their knowledge (Dierks, 1981)

Research Questions

1. Does mathematical prior knowledge and everyday experiences interfere with high school chemistry students' understanding and application of certain basic chemical concepts?
2. Do students differentiate between selected mathematical and chemical concepts that have the same name but different meanings and uses?

Theoretical Framework

The underlying theoretical framework of this study was the constructivist view of learning and Ausubel's theory of meaningful learning. It helps to explain why students bring prescientific conceptions to the science classroom and why these conceptions are resistent to instruction (Bodner, 1986; Dreyfus, Jungwirth, & Eliovitch, 1990; Driver & Easley, 1978; West, Fensham, & Garrard, 1985). Also, it assumes that learning science is an active process of construction and reconstruction of knowledge and is heavily dependent on prior knowledge (Bodner, 1986; Braathen & Hewson, 1988; Resnick, 1983; Wheatley, 1991). Learning science, therefore, involves students in not only adopting new ideas but also in modifying or abandoning their preexisting ones (Scott, Dyson, & Galer, 1987). Prior knowledge affects students' comprehension (Champagne & Bunce, 1991), determines what information will be selected (Glynn, Yeany, & Britton, 1991), influences what students remember (Champagne & Bunce, 1991), and is one of the most important variables that affect learning science (West & Fensham, 1979).

Related literature

Chemical Symbols. Dierks (1981) pointed out in his study that the ambiguity and the customary and initial use of chemical symbols contribute to students' difficulties. Other researchers (Dierks, Weninger, & Herron, 1985a, 1985b; Nechamkin, 1975; Schmidt, 1984, 1986) concluded from their studies that symbols often have little or no basis in reality for the student and that similar chemical symbols have different meanings. They also found that students have little knowledge of the meaning of the chemical symbols. Additionally, Gabel, Samuel, and Hunn (1987); Herron (1975); and Schmidt (1984, 1989) believed that students do not understand chemical symbols. This resulted in many difficulties for meaningful learning. Other researchers (Niaz & Lawson, 1985; Savoy, 1988; Yarroch, 1984, 1985) found that students have difficulties with symbols as abstractions and with their mathematical manipulation. Herron (1975) and Schmidt (1984) indicated in their studies that the students do not have any conception of the difference between H^+, H, and H_2 nor between O and O_2.

Chemical Formulas. Students' difficulties, as related to chemical formulas, appear to have multiple causes. Students are not aware of the similarities and differences between chemical and mathematical formulas (Brown, 1984; Dierks, 1981). Also, they do not differentiate between subscripts of chemical formulas and coefficients in chemical equations (Lazonby, Morris, & Waddington, 1982; Schmidt, 1984, 1990; Yarroch, 1985). Moreover, many students perceive a chemical formula as representing one unit of a substance rather than a collection of molecules. This, then, leaves them not understanding the meaning of subscripts and symbols (Ben-Zui, Eylon, & Silberstein, 1986, 1988a, 1988b). Also, Niaz and Lawson (1985) and Savoy (1988) believed that students do not understand the meaning of formulas and simply attempt to memorize everything.

Chemical Equations. Alberty (1991) said, "chemists tend to think that chemical equations are unique to chemistry, and they are not used to thinking of chemical equations as the mathematical equation they really are" (p. 984). Kolb (1978) believed the term chemical equation is misleading and confusing. She said

> ... in a chemical equation, what is on the left is not really equal to what is on the right ... a chemical equation is really just a concise statement describing a chemical reaction, expressed in chemical symbolism . . . strictly speaking one does not "balance an equation," since if it truly is an equation, it is already balanced. Perhaps we can think of unbalanced chemical statements as incomplete equations (pp. 184-185)

A number of researchers pointed out students' conceptual difficulties as they relate to chemical equations in the writing, understanding, manipulation, and balancing of chemical equations. Ben-Zui, Eylon, and Silberstein (1987), and Ross (1989) assumed that understanding, balancing, and interpreting chemical equations depend on understanding the structure and physical state of the reactants and products, the dynamic nature of particular interaction, the qualitative relationships among the particles, and the large number of particles involved. Nakhleh (1992) attributed students' prescientific conceptions of chemical equilibrium to the lack of chemical knowledge concerning how to regard and apply symbolism of a chemical equation. Hesse and Andersson (1992) pointed out that the lack of mastering conceptual ecology of chemistry contributed to students' difficulties. Staver and Jacks (1988) found that students' understanding of chemical formulas significantly influences overall equation balancing performance.

Savoy (1988), Schmidt (1984, 1986, 1989), and Yarroch (1985) concluded from their studies that many students do not differentiate between subscripts of chemical formulas and coefficients in chemical equations. Also, they possess a poor understanding of those two concepts and are willing to violate the chemical equation balancing rules. Other researchers (Savoy, 1988) believe that the lack of knowledge of valency numbers and a failure to understand concepts, such as atomicity, use of brackets, and the significance of subscripts and coefficients, contribute to students' difficulties. Gabel, Samuel, and Hunn (1987) and Yarroch (1984, 1985) concluded that the lack of performing simple arithmetic operations involved the lack of understanding the chemical concepts and their significance as well as students' inability to read and interpret scientific language all contributed to students' difficulties in chemistry. Moreover, Staver and Jacks (1988) found that students' understanding of chemical formulas significantly influences overall chemical equation balancing performance. Filgueiras (1992) found that the beginning student equates chemical equations with actual reactions.

Krajcik (1991) found that most of the students master the technique of balancing a chemical equation by picturing a chemical equation as a mathematical puzzle in which the number of atoms on each side of the equation has to equal each other. Also, understanding the underlying chemical concepts represented in elementary chemical equations requires students to have an integrated understanding of chemical concepts. Creenbowe (1984) and Nakhleh (1992) indicated that many students perceive balancing chemical equations as strictly algorithmic. Yarroch (1985) found that the majority of students view chemical equation balancing as mechanical manipulation of symbols. Savoy (1988) concluded that the students' lack of understanding the basic chemical concepts contributed to their difficulties in balancing chemical equations.

Coefficients and Subscripts. Ben-Zui, Eylon, and Silberstein (1987); Hackling and Garnett (1985); Savoy (1988); and Yarroch (1989) found in their studies that students lacked understanding of the significance and function of coefficients and subscripts in formulas and equations. Besides, Lazonby, Morris, and Waddington (1982); Savoy (1988); Schmidt (1984); and Yarroch (1985) concluded from their studies that students confused stoichiometric coefficients in equations with subscripts in formulas.

<u>Arrow Sign (→)</u>. Yarroch (1985) indicated in his study that the first group of students believed that the reaction symbol (→) had the same connotation as a mathematical equal sign (=) and more than just an equal sign. The second group of students described the chemical reaction symbol as simply a mathematical equal sign. Weninger (1982) addressed the inconsistencies in the way various symbols, such as equal sign (=) and arrow sign (→), are used in chemistry classes. He called for more precise use of symbolic language.

Material and Methods

A combination of qualitative and quantitative methods were used to conduct this study in two stages. First, open-ended essay questions were used in the preliminary study. Second, clinical interviews were used in the main study. Additionally, throughout the study, the classroom teacher was an active participant consultant in the research process.

The preliminary study was conducted in two chemistry classes (42 students, 11th grade at a university Laboratory High School) during the fall semester of 1990. Immediately after the chemistry teacher taught the concepts chemical symbol, formula, and equation, three open-ended essay questions (see Appendix A) were given to the students in three consecutive periods. Content analysis using preestablished criteria as well as two group of experts were used to analyze the obtained data. The finding of this piolt study were the framework for the development of the main study.

It was concluded from these findings (see Appendix B) that a large portion of the students' responses were vague, confusing, and suggested the existence of prescientific conceptions. More than half of the students had little understanding of these basic chemical concepts. The students were not aware of the chemical application, the use, the significance, or the relationships among these concepts. Also, these findings show that some students did not distinguish between the mathematical and chemical use and meaning; some of the students responded to the questions from a mathematical point of view.

The Main Study. The main study was the second stage of this research project. It focused upon the findings from the preliminary study and was conducted on the teacher selected sample (18 students) at the same high school. The clinical interview approach was used as a research method throughout this study, the subjects' chemistry teacher was an active participant, and content analysis was used for data analysis.

Sampling . The sample was chosen from the same students (42 students, 11th grade at LSU's Laboratory High School) who participated in the preliminary study. The chemistry teacher chose a sample of 18 students out of 42 students. The members of the sample were representative of three achievement levels (upper, middle, and lower groups). The sample was partitioned according to students' gender and their achievement in high school chemistry.

Clinical Interview. The primary purpose of the interviews was to investigate, in depth, students' conceptions of certain basic chemical concepts as well the rules and laws required for application and manipulation. Each individual interview was audio taped and lasted about 20-30 minutes. In current science education research, the qualitative research method used most often for gathering data about what children know is some variation of the clinical interview (Lythcott & Duschl, 1990). The clinical interview developed by Piaget was used since it is recognized as a superior method for detecting students' conceptions and conceptual change (Stepans, 1991). Current techniques use modification of the classical interview. The two most commonly used procedures are interviews about instances and interviews about events (Lythcott & Duschl, 1990; Osborne & Cosgrove, 1983; Treagust, 1988). The clinical interview method and its modifications have proved to be the most fruitful for generating rich data (Lythcott & Duschl, 1990).

Data Collection. Three activities presented to the students involved chemical substances, chemical apparatus, three actual chemical reactions which also were represented on cards , and a follow-up interview card. For each activity, students were asked to explain and answer each question in their own words. The researcher used the clinical interview method for data collection. The interviewing process was pilot-tested with the first three students and the resulting feedback used to make the necessary revisions in the following interviews. The clinical interviews were conducted using an established interviewing protocol and process. Moreover, the researchers involved the students in three activities (three chemical reactions):

1. Activity No. 1: Magnesium burns in air (combines with oxygen) and forms magnesium oxide.

$$2Mg + O_2 \rightarrow 2MgO$$

2. Activity No. 2: Sodium reacts with water to produce hydrogen and sodium hydroxide.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

3. Activity No. 3: Copper replaces silver in a solution of silver nitrate, producing copper (II) nitrate and silver.

$$Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$$

Each student was interviewed three times. Each time, the researcher demonstrated a different chemical reaction and presented the corresponding interview card. Each interview was tape-recorded and lasted approximately 20-30 minutes (Novak & Gowin, 1989).

Data Analysis. The data collected consisted of the students' interviews (verbal responses), students' written responses, and the researcher's comments. Each tape for each student was played twice and then transcribed verbatim and combined with his/her written responses and the researcher's comments. A record file was established for each of the interviewed students. It consisted of a student's profile, interviews, written responses, the researcher's comments, and the transcripts. The process of data analysis was based on the suggestions, recommendations, and methods addressed by Finley (1984), Gilbert, Watts, and Osborne (1985), Novak and Gowin (1984), Patton (1990), and Wandersee (1983).

Based on the established criteria and the suggestions of two groups of experts, the researchers examined each student's transcript and analyzed the data(see the following figure) according to the following stages:

1. Content analysis was used to examine each student's transcript in order to establish a conceptual inventory of the students' ideas (Wandersee, 1983). Each statement was considered as a single proposition on a small scale of related propositions (Finley, 1984). The ideas that deviated from the established criteria were identified, listed, and then classified into eleven categories corresponding to eleven basic chemical concepts: chemical reaction, chemical reaction representation, chemical symbol, chemical formula, chemical equation, reactants and products, plus sign (+), arrow sign (→), balancing chemical equation, subscript, and coefficient.

2. The students' conceptual inventories were combined in order to collate all the students' relevant ideas under the same categories. The students' propositional statements relating to the eleven key chemical concepts were organized, tallied, and classified. The resulting categories contained not only the most common and prevalent ideas but also the most relevant, related propositional statements. Subsequently, all the findings (the students' conceptual indicators of possible prescientific conceptions) for each concept were presented in a separate table (see Appendix H).

3. The final stage of data analysis yielded a descriptive discussion, theoretical interpretation, and summary of the findings related to each concept. Also, selected representative excerpts from the students' transcripts were used to support the findings.

Student's record files: Student's profiles, taped interviews, written responses, and researcher's notes.

Student's transcripts: Transcribed the clinical interviews combined with the student's written responses and the researcher's notes.

Student's conceptual inventory: Categorized student's ideas into eleven basic chemical concepts.

Student's conceptual indicators: Tallied/collated the number of the students who had relevant ideas/propositions about a single chemical concept.

The findings: Tabulated students' possible prescientific conceptions.

Figure 1. Flow diagram of data analysis process.

Results and discussion

The resulting indicators of the students' conceptual difficulties were categorized into the following sections

Chemical Symbols

Students' conceptions of three chemical symbols (Mg, Na and Cu) were investigated and were classified. Half of the students (six males and three females) assumed in their conceptions that the chief use of the symbol Mg is *shorthand writing*. For example, a student (female) from the upper group said, " . . . a chemical symbol is just a shorthand method of writing an element's name . . . instead of writing magnesium, they just write Mg . . . much quicker . . . ." One-third of the students (four males and two females) believed that the main use of a chemical symbol is to save time. For example, a student (male) from the lower group said, " . . . chemical symbols are the short version . . . to save time and paper . . . you can do it quick . . . ."

Two-thirds of the students (five males and seven females) assumed that the main significance of the chemical symbol Na is easier to use. For example, a student from the lower group said, ". . . chemists use chemical symbols because it is easier and faster . . . ." One-third of the students (three males and three females) believed that the chemical symbol Na is just a shorthand writing. For example, a student (male) from the middle group said, " . . . a symbol is a shorthand method for elements . . . ." Four students (two males and two females) pointed out in their responses that chemical symbols are used in chemistry *to save time. For example, a student from the middle group said, ". . . chemists use chemical symbols because they don't have to write out the word, and to save time . . . ."*

About one-third of the students (three males and four females) indicated in their answers that the chemist uses the chemical symbol Cu because it is easier. For example, a student from the middle group said, " . . . chemists use chemical symbols to make it easier for them instead of writing the whole names . . . ."

Discussion. Students assumed that the main significance of a chemical symbol is shorthand writing, saves time, and saves space. Related studies indicated some of these findings. Glassman (1967) found in his study that the students had persistent ideas of the use of symbols for saving time.

These ideas are valid and applicable nearly on chemical symbols, mathematical symbols, everyday symbols, etc. It seems that the students' prior mathematical knowledge contributed to their conceptual difficulty about the concept of a chemical symbol. They transferred their conception of the concept symbol from their prior knowledge. They had vague and too general an understanding of the concept symbol. They confused the concept symbol in mathematics and everyday life with the concept chemical symbol. They were not aware that each chemical symbol was assigned to certain elements and indicates specific knowledge. Other researchers found similar results but had different conclusion. Werner (1981) believed that the customary and initial use of chemical symbols to characterize substances seems to hamper the process of comprehension on the part of the learner. Gabel, Samuel, and Hunn (1987) found that the students did not understand the symbols chemists use to represent the macroscopic and microscopic levels.

Chemical Formulas

Students' conceptions of six chemical formulas (O_2, MgO, H_2O, H_2, $AgNO_3$ and $Cu(NO_3)_2$) were investigated and the conceptual difficulties were classified and discussed.

Eight of the students (five males and three females) conceived a chemical formula as a chemical equation. For example, a student (female) from the middle group wrote, ". . . $Mg + heat \rightarrow MgO_2$ is a chemical formula . . ."

Three students (one male and two females) assumed that a chemical formula is used to equate the problem. For example, a student (male) from the middle group said, ". . . a chemical formula is used to equate the problem . . ."

Five students thought that the main uses of the chemical formulas are easy to use. For example, a student (female) from the middle group said, " . . . chemists use chemical formulas because they are universal, easy to use . . . and I really know what they mean . . . ."

About half of the students (five males and three females) indicated in their answers that the chemical formula is a chemical equation. For example, a student (male) from the upper group wrote, "$H_2O + Na \rightarrow H_2 + NaO$ is a chemical formula."

Five students (three males and two females) pointed out in their answers that chemists use the chemical formulas($AgNO_3$ and $Cu(NO_3)_2$) because *it is easier*. For example, a student (female) from the middle group said, " . . . chemists use chemical formulas because it takes too much time to write the words . . . it is an easier way to write it down . . . . "

Nearly half of the students assumed in their answers that the reactants $Mg + O_2$, $Na + H_2O$ and $Cu + AgNO_3$ were chemical formulas. They confused the concept reactant wit the concept formula. Also, about half of the students assumed that the products $NaOH + H_2$ and $Cu(NO_3)_2 + Ag$ were chemical formulas.

Discussion. The students confused the concept chemical formula with the concept chemical symbol, the concept chemical equation, the concept reactants, and the concept products. Some researchers indicated different results. Eylon, Ben-Zui, and Silberstein (1987) found that 25% of chemistry high school students were unable to represent a chemical formula for a simple molecule formula as representing one unit of a substance rather than a collection of molecules.

It seems that the students relied on their prior conceptions of the concept formula. Consequently, they had those conceptual difficulties. The students assumed the presence of the plus sign (+) in the chemical formula. Therefore, confused the concept of chemical formula with the chemical equations, the reactants, and the products. Glassman (1967) found similar results. He indicated that the students believed that a chemical formula tells in some way how to perform an experiment. Also, he indicated that the students believed that a chemical formula was an abbreviation for a name, and only compounds have formulas.

Chemical Equations

Students' conceptions of three chemical equations($2Mg + O_2 \rightarrow 2MgO$, $2Na + 2H_2O \rightarrow 2NaOH + H_2$, $Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$) were investigated and the findings were classified

Four students (two males and two females) assumed that *a chemical equation explains better than words. For example, a student (female) from the upper group said, ". . . a chemical equation is a way of shorthand writing . . . it explains better than words." Four students (one male and three females) pointed out that a chemical equation is a way of shorthand writing. For example, a student from the upper group said, " . . . they just use equations to show shorthand... I guess a chemical equation represents things added together and that they yield without, say, the experiment."*

At the end of the last interview, each student was presented with a sheet of paper with the following chemical equations,

$2Mg + O_2 \rightarrow 2MgO$

$2Na + 2H_2O \rightarrow 2NaOH + H_2$

$Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$

then asked to draw a rectangle around each chemical equation. A few students could not recognize a chemical equation. their answers can be divided into two groups regarding their conceptions: The first group believed that the chemical reactants (the left side of a chemical equation) were a chemical equation; for example, three students believed that $Mg + O_2$, $Na + 2H_2O$, *and* $Cu + 2AgNO_3$ *were chemical equations. The second group assumed that the chemical products (the right side of a chemical equation) were a chemical equation. For example, three students (one male and two females) believed that* $2MgO$, $2NaOH + H_2$, *and* $Cu(NO_3)_2 + 2Ag$ *were chemical equations.*

Discussion. It seems that the students did not master the main significance of a chemical equation. Their answers were vague, incomplete, and lacked important ideas. Glassman (1967) found similar results. He indicated that students had difficulties writing and using chemical equations, confused chemical equations with chemical formulas, and had naive and vague conceptions of chemical equations.

It seems that the students had poor understanding of the quantitative and qualitative aspects of a chemical equation. A chemical equation explains better than words, a way of shorthand writing, it shows you how much of something you need, a lot easier, shows what was started with, and shows what chemists use. These findings are supported by other studies. Yarroch (1985) pointed out that the students ignored the law and theories that give meanings to chemical symbols and transferred equation writing into a mathematical game of getting the symbols to add up on both sides of imaginary equal sign. Nakhleh (1992) concluded from his review that the students' prescientific conceptions of chemical equilibrium indicated that the students lacked extensive or securely-based knowledge concerning how to regard and apply to symbolism of a chemical equation.

Those ideas indicate that the students did not master the concept of chemical equation. It seems that prior chemical knowledge (their conceptual difficulties of the concepts of chemical symbol, chemical formula, the reactants, and the products) and their prior mathematical knowledge (their mathematical conception of the concept of equation) contributed to their conceptual difficulties of the concept of chemical equation.

Plus Sign (+)

Students' conceptions of the plus sign (+) in three chemical equations were investigated. The related results are classified into two categories: The students' ideas of the plus sign (+) between the reactants, and the students' ideas of the plus sign (+) between the products.

Most of the students (six males and five females) read the + as a plus sign in both sides of a chemical equation . For example, a student (male) from the middle group said, " . . . I read + on the left side + . . . it means along with, together . . . ." Seven students (three males and four females) pointed out in their answers that the + means added to. For example, a student (male) from the middle group said, " . . . on the left side plus, add to . . . and on the right side you read it the same . . . ." Six students (two males and four females) thought that the + means added together. For example, a student (female) from the middle group said, " . . . together with, like plus, adding them together to yield the answer . . . ." Two students (one male and one female) believed that + is an addition sign. For example, a student (male) from the upper group said, " . . . it looks like addition, more like math . . . ."

The second group of the students had different conceptions of the plus (+) between the reactants. Eight students (three males and five females) believed that the + means combine with. For example, a student (female) from the lower group said, " . . . on the left combine . . . on the right means combine . . . ." Two students (one male and one female) pointed out in their answers that the + meant the same in both sides of a chemical equation. For example, a student (female) from the upper group said, " . . . They mean the same. This is showing you the reaction occurring . . . this is the result . . . I read both plus . . . ."

Two students (two females) believed that the + is a plus sign. For example, a student (female) from the lower group said, " . . . I read it plus and it means plus things together . . . I don't know . . . ." One student (female) believed that the + had the same meaning in both sides of a chemical equation. For example, a student (female) from the lower group said, " . . . on the left means combine . . . on the right means combine . . . ." One student (male, assumed in his answer that the + means end up with. For example, a student (male) from the upper group said, " . . . the + means ended up with more than one product . . . ."

Discussion. It seems that the students confused the significance and meaning of the plus sign (+) in a chemical equation (the plus sign (+) between the reactants and the plus sign (+) between the products), with the plus sign (+) in a mathematical equation/mathematical formula.

The students assumed that the plus sign (+) between the reactants means added to, added together, something is going to react, combines, and the same in both sides of a chemical equation. Also, they believed that it is an addition sign (+). Moreover, the students had a few conceptual difficulties regarding the plus sign (+) between the products. They believed it is a plus sign (+), means the same as the plus sign between the reactants, means end up with, and means leftover.

Arrow Sign (→)

The related results indicate that the students had little conceptual difficulties concerning the reaction sign (→) in a chemical equation. Most of the students (eight males and eight females) were aware of the use and meaning of the reaction sign (→) in a chemical equation. The remainder of the students had vague understanding of the reaction sing (→). For example, a student (female) from the upper group said, " . . . the arrow shows two (Mg + O_2) yield and there is a reaction . . . ." One student (female) believed that the → is an equal sign. For example, a student (female) from the lower group said, " . . . it is a symbol . . . it is like showing what happened or yields, says this makes whatever, kind of like an equal sign . . . ." One student (male) assumed that the reaction sign (→) means produce. For example, a student (female) from the lower group said, " . . . I read (→) yields, produce . . . . " One student (male) believed that the (→) means the reaction. For example, a student (male) from the lower group said, " . . . it means the reaction, what is yield over here . . . ." One student (female) used the words yield and create as synonyms to indicate the (→) meaning. Two students (males) conceived the (→) as result in. For example, a student (male) from the upper group said, " . . . it is yield, results in this . . . ."

Discussion. Some of the interviewed students believed that the reaction sign (→) is an equal sign. Also, they assumed that it means produce, the reaction, create, and result in. Yarroch (1985) indicated in his study that the first group of students believed that the reaction symbol (→) had the same connotation as a mathematical equal sign (=) and more than just an equal sign. The second group of the students described the chemical reaction symbol as simply a mathematical equal sign. It seems that the students' mathematical knowledge and everyday conception of the arrow sign (→) interfered in their conception of the reaction sign (→) to some extent. The majority of the interviewed students mastered the meaning and significance of the arrow sign (→) in a chemical equation.

The Relationships Between the Coefficients and Subscripts

Students' conceptions of the relationships between coefficients and subscripts were investigated. The students were presented with the following formulas and ions: 10 H_2, 2NaOH, $5Cu(NO_3)_2$, $3AgNO_3$, $2CO_3$, and $4NH_4$. The students' ideas are classified into five groups.

The first group added up the coefficient(s) and the subscript(s) to get the total number of atoms in a chemical formula/ion. Two students (one male and one female) believed that 10 H_2 has 12 hydrogen atoms. Two students (females) assumed that $2Cu(NO_3)_2$ has 10 oxygen atoms. They *added up the parenthesis* subscripts (2), the oxygen

subscript (3) and the coefficient (5) to get the total number of oxygen atoms. Four students (one male and three females) pointed out that $3AgNO_3$ has 6 hydrogen atoms. Three students (females) thought that $2CO_3$ has 5 oxygen atoms. Five students (one male and four females) believed that $4NH_4$ has 8 hydrogen atoms.

The second group ignored the subscript(s) when they counted the number of atom(s) in a chemical formula or an ion. Two students (females) assumed that 10 H_2 has 10 hydrogen atoms; two students (one male and one female) thought that $2CO_3$ has 2 oxygen atoms; and one student (female) believed that $4NH_4$ has 4 hydrogen atoms.

The third group ignored the coefficient(s) when they counted the number of atoms in a chemical formula or an ion. Two students (one male and lone female) believed that 2NaOH has 1 hydrogen atom, one student (male) assumed that $5Cu(NO_3)_2$ has 6 oxygen atoms, and one student (female) pointed out in her answer that $3AgNO_3$ has 3 oxygen atoms.

The fourth group multiplied the parenthesis subscript by the ion subscript then added the sum to the coefficient. Three students (one male and two females) pointed out in their responses that $5Cu(NO_3)_2$ has 11 oxygen atoms. They multiplied 2 x 3 then added the sum (6) to the coefficient (5) to get the total: $5 + 6 = 11$ oxygen atoms.

The fifth group considered the ions' charges when they counted the number of atom(s) in an ion(s). Two students (females) pointed out that $2CO_3$ has 1 oxygen atom. They subtracted the ion charge (-2) from the subscript (3) then ignored the coefficient to get the total of one oxygen atom. Three students (females) subtracted the ion charge (-2) from the coefficient (2) to get the total oxygen atom of three in $2CO_3$; one student (male) subtracted the ion charge (-2) from the subscript (3) and considered the coefficient (2) to get the total of two oxygen atoms in $2CO_3$; and one student (female) assumed that $4NH_4$ has 17 hydrogen atoms. She multiplied the coefficient (4) by the subscript (4), then added up the ion charge (+1) to get the total hydrogen atom number of 17.

Discussion. It seems that the students had conceptual difficulties understanding the relationships between the subscripts and coefficients in a chemical concept. The students added up the parenthesis subscript(s), ignored the subscript(s), ignored the coefficient(s), multiplied the subscripts and added up the sum to the coefficient, considered the ion's charges, added up the subscript(s) to the coefficients, and ignored the coefficients. Some of these findings are supported by other studies. Lazonby, Morris, and Woddington (1982) noticed that many students presented with $2Ag_2O$ are unsure which two meant what. Also, Savoy (1988) found that the students did not realize the difference between CaO_3 and $3CaCO_3$ and K_2 and 2K. The students had misunderstanding of the significance of subscripts and coefficients.

It seems that the students confused the subscripts with the coefficients and transferred their prior mathematical knowledge of the relationships between the coefficients and subscripts to the chemical concept. They failed to differentiate the relationships between and significance of the subscripts and coefficients in a chemical concept and mathematical concept.

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

Findings

About one-third of the interviewed students held common prescientific conceptions and the rest of the students (two thirds) held unique conceptions. These prescientific conceptions were common and prevalent among the students regardless of achievement level, sex, age, interest, and prior knowledge. Also, these conceptions seemed to have different causes/sources, characteristics(quantitative and qualitative in nature), and prevalence. The findings were classified into six categories

Chemical Symbols. Students assumed that a chemical symbol is shorthand writing, and used to save time. Also, they believed that O_2 and H_2 are chemical symbols. They had little understanding of the role of the subscript in a chemical symbol. It seems that those students did not understand the main significance of a chemical symbol. They were not aware that a chemical symbol implies specific knowledge.

Chemical Formulas. The students confused the chemical formulas with the chemical equations. The students assumed the presence of the plus sign (+) in the chemical formula . Also, they believed that a chemical formula is used to equate a problem, and easier to use. It seems that the students' prior mathematical knowledge and experience of the concept formula contributed to their prescientific conceptions.

Chemical Equations. Students believed that the main significance of a chemical equation is to explain better than words, to serve as shorthand writing, and to be easier to write. Also,they believe that they use chemical symbols only to write chemical equations. It seems that the students' prior knowledge of the concept of equation contributed to their prescientific conceptions of the chemical equations.

Plus Sign (+). The students ideas show that they did not master the meaning nor significance of the plus sign (+) between the reactants and between the products. It seems that their prior conception of the plus sign (+) interfered in their conception of the plus sign (+) in a chemical equation. They confused the meaning and significance of the plus sign (+) between the reactants and between the products with the meaning and significance of the plus sign (+) in a mathematical/everyday problem.

The Reaction Sign (→). It seems that a few students had possible prescientific conceptions: One student (one female) indicated in her answer that the chemical reaction sign (→) is an equal sign, one student (one male) believed that the reaction sign (→) means produces, one student (one male) assumed that the reaction sign (→) means the reaction, and one student (one male) thought that the reaction sign (→) means results in. Those students might have transferred their prior conceptions of their mathematical and everyday life of the concept arrow sign (→) to understand the chemical reaction sign (→).

The Relationships Between the Coefficients and Subscripts. The students added up the coefficient and the subscript to get the total number of specific element atoms, they ignored the subscript and considered the coefficient, they ignored the coefficient and considered the subscript, they multiplied the parenthesis subscript by the ion subscript and then added the sum to the coefficient, and/or considered the ion charges in their calculations.

Those students used their prior knowledge (mathematical and everyday experiences) of the relationship between the concepts coefficients and subscripts in these chemical concepts. The students failed to realize that the relationship between the coefficients and subscripts are different in a chemical problem and a mathematical/everyday problem.

Conclusions

The findings of this study indicate that the beginning high school chemistry students hold possible prescientific conceptions about the basic concepts even after one year of instruction. Also, the researcher was led to the conclusion that certain patterns emerged (key findings), were common to all of the interviewed students:(1) students seemed to confused the basic chemical concepts with the similar mathematical ones, (2) nearly, all the students' answers and ideas were vague, too general, not accurate, and did not reflect a clear understandings, (3) the students confused basic chemical concepts with one another, (4) the identified prescientific conceptions were prevalent among students regardless of age, sex, achievement level, interest, and prior knowledge, (5) students treated some chemical concepts as mathematical concepts, (6) students' prior mathematical knowledge contributed to their prescientific conceptions, and (7) one-third of the students shared the same prescientific conceptions and two-thirds had their individual ones.

Implications

Chemistry Instruction

Chemistry teachers should not underestimate the role of students' prior knowledge, ideas, and theories in the learning process. Teachers should be aware that these basic chemical concepts are often taught and introduced to the students in a manner that will not be consistent with their prior knowledge (mathematical and everyday experiences). Therefore, teachers should probe their students' conceptions of each chemical concept in order to evaluate the students' difficulties and comprehension of mastering that chemical concept before introducing a new related concept. Also, chemistry teachers should develop their teaching strategies for initiating conceptual change

Chemistry Textbooks. Curriculum developers should reduce the number of concepts introduced to high school students in order to allow more time and emphasis on the basic concepts which are the base for future chemical education. Also, curriculum developers should elaborate on these basic concepts regarding their significance, application , definitions, relationships, and so on. Also, clarify the similarities and differences between the chemical concepts and the similar mathematical concepts.

Limitations and Future Research

This exploratory study investigated 18 high school chemistry students' conceptions of certain basic chemical concepts. The findings provided evidence which suggests that beginning high school chemistry students may harbor prescientific conceptions regarding these basic chemical concepts. Consequently, it seems prudent to repeat this study on different populations and on larger samples in order to verify the findings and to seek more generalizable results.

The limitations of this study were due mainly to the use of the clinical interviews and the use of a small sample size to conduct the main study. Interview data always present a unique challenging problem for data analysis and generalizability of the results. The interviewed students may have relied on their everyday language and macroscopic level of understanding to respond to the interviewer's questions, in spite of the interviewer's explicit search for scientific understanding. Also, the possibility exists that students might not have understood the interviewer's questions. In order to minimize this problem, the researcher used a semistructed interviewing process, and pilot-tested the interviewing process with feedback. Also, the researcher conducted follow-up interviews to clarify any ambiguity of the students' language and to probe students' current conceptions. Each student was presented with a transcript of his/her ideas to determine whether or not he/she agreed with the interviewer's interpretations. In spite of these safeguards, however, it is possible that the students' responses were misinterpreted by the researcher. Having independent checks for validity by more than one researcher would help to reduce the effects of this problem. Interpreting the meaning of language is always a difficult task. In addition, concept mapping could be used to examine students' (and teachers') understanding of the concepts of interest to the researcher. Self-constructed maps reduce can the danger of misinterpretation and serve as a basis for follow-up interviews in which any problematic elements of the map can be discussed with the concept mapper.

Further investigation of students' conceptions of these basic chemical concepts may contribute to chemistry education and curriculum development on a large scale. It seems premature to investigate students' understanding of more complex or advanced chemical concepts until chemistry educators understand how to teach the basic concepts well.

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