

First-Year College Students' Knowledge in Chemistry: Is It Adequate?

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Abstract A total of 502 randomly selected incoming freshmen students were asked to answer Chemical Concepts Inventory questionnaire containing 22 multiple choice questions. These students graduated from a total of 150 private and public high schools. The sample is composed of 273 female and 229 male students. The Chemical Concepts Inventory developed by Mulford was meant to measure students' conceptual understanding of common topics taken in a general chemistry class as well as alternate conceptions on these topics. Results indicated that these sampled high school graduates were not able to fully master some basic concepts in chemistry. Female and male students have mean scores of 4.63 and 4.75 respectively. Further analysis using t test of independent samples revealed that the mean scores did not differ significantly when students are grouped according to gender and type of school. This may indicate that these students did not fully understand the concepts covered in the inventory during their high school chemistry.

Keywords: *conceptual understanding, chemistry achievement, alternate conceptions*

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1. Introduction

Students entering college have varying degree of preparation and abilities in science and mathematics. General chemistry is a common course which majority of college students take. Research indicated that students' achievement in chemistry is in need of improvement as majority of these students are afraid and do not possess confidence to succeed in chemistry. Their fear of chemistry stemmed from the perceived difficulty of the subject and its degree of abstraction. High school chemistry pedagogical experiences do appear to play significant roles in the future success of students in introductory college chemistry courses [1], however college chemistry teachers have little control in the quality of college entrants in terms of chemistry concepts mastery. It is necessary for college science teachers to ensure that the college chemistry teaching will bridge what has been learned in high school with college chemistry and to correct misconceptions if present. The use of an evaluative tool is therefore necessary to address this concern. Knowing what the students have learned in high school chemistry will help college chemistry teachers plan for intervention. The college chemistry teachers can also devote more time to the concepts that are helpful to the understanding of higher concepts.

Many of the students enrolled in general chemistry have apprehension about the course and are unsure of their ability to succeed [2]. The intrinsic nature of the subject and the psychology of human learning have caused the

perception that chemistry is a difficult subject [3]. In addition, the psychology for the formation of most of chemical concepts is quite different from that of the 'normal' world. Teachers have added to this complication by operating on and interrelating three levels of thought: the macro and tangible, the sub micro atomic and molecular, and the representational use of symbols and mathematics. The simultaneous introduction of these three levels often results to students' misconception.

Mulford's Chemical Concept Inventory (CCI) has questions that probe student's conceptual understanding. CCI is a multiple choice instrument that can be used to indicate the level of chemistry misconceptions held by students. The inventory is a multiple choice instrument composed of one- and two-tiered non-mathematical conceptual questions (22 questions total). The questions are based on common commonly-observed student misconceptions about topics generally covered in the first semester of a college chemistry course. The inventory was administered to over 1400 students in a general chemistry course for science and engineering majors (all of whom have had a high school chemistry course) during the first week of a fall semester and repeated during the first week of the following spring semester. The average grade on the inventory was 45% (10 of 22) in the fall and 50% (11 of 22) the following spring.

Many of general chemistry students are not fluent with a significant portion of the concepts in general chemistry [4]. The students have difficulty with fundamental concepts concerning the properties and behavior of atoms and molecules. They cited as an illustration the results from two semesters of high school chemistry and one

semester of general chemistry. The findings indicated that 47% of the students believe that the rust from a completely rusted iron nail weighs less than the nail it came from. It was also found out that 75% of the general chemistry students cannot distinguish between the properties of a single atom of sulfur and a sample of solid sulfur; and 65% of the students believe that breaking chemical bonds gives off energy.

What could be the reason for this dismal performance in general chemistry? The researcher believes that this could be partly attributed to the kind of assessment questions used by the science teachers as well as the teaching approach. There are three categories of assessment questions. These are recall, algorithmic and higher order. College and high school chemistry teachers may choose from the different categories of questions when assessing their students' understanding of the concepts. In general, students are studying to pass the subject and the kinds of questions given in test are more on knowledge questions that require recall. Students therefore, tend to memorize facts without truly understanding the concepts involved. Conceptual questions can help students' achievement because conceptual questions are higher-order questions. As such, they may assess student understanding of the underlying ideas behind chemical phenomena. Conceptual question require students to explain an unfamiliar phenomenon. Students are tested in their ability to transfer of knowledge to a new situation. By using conceptual questions, teachers are training students to adapt an explanation to a new situation and identify the underlying concept in order to recognize which algorithm to invoke. Students learn to visualize a system and use it to reach a conclusion. Moreover, the use of conceptual questions develops students' ability to analyze information to select relevant data. Frequent and proper use of conceptual understanding question will help teachers and students realized that there is more than one acceptable answer. Not only that, conceptual understanding questions can be used in the science classrooms for opportunities for learning and evaluation of learning at the same time.

Chemistry achievement may be improved by the use of conceptual questions. Students are able to solve problem solving items in chemistry successfully if conceptual understanding is attained first [5]. Conceptual questions present a chemical situation that a student has not trained with and ask the student to justify a choice and make predictions. Students are trained to explain the causes of events and phenomena, link two or more concepts, and extract data from various sources of information.

Bruner's Discovery Theory stipulates that curriculum change must be based on the idea that learning is an active, social process in which students construct new ideas or concepts based on their current knowledge. Moreover, Bruner maintains that students must be ready to learn. This means that instruction must be concerned with the experiences and contexts that make the student willing and able to learn. He also proposed that instruction must be spiral in organization to help students grasp concepts easily while training the students to go beyond the information given. However, chemistry is generally appealing to introverts perhaps because the study of chemistry mainly involves individual work. Chemistry also has more judgers than perceivers, possibly reflecting

the logical, systematic and formal way that it is taught, which appeals to judgers [6]. The researcher therefore believes that improving chemistry achievement is a complex process and knowing what most students failed to understand regardless of gender and type of high school graduated from is already a good start towards the achievement of that goal.

2. Methods

The researcher randomly sampled 525 incoming first year college students' conceptual understanding in general chemistry through Mulford's Chemical Concepts Inventory. The data gathering was done during the months of April and May. These are the months that university entrants take the entrance examination. Permission was obtained from the Office of Admission and Scholarship. The survey questionnaire was given after the students have taken the standardized admission test. The respondents were randomly selected. For example, in one data gathering schedule, all the students taking the entrance examination in the morning were given the survey questionnaire. During the next data gathering schedule, all the students taking entrance test in the afternoon were given the survey questionnaire. This was done at different intervals until the 525 sample size was reached. Out of the 525, only 502 were found useful based on the completeness of profile information. The data gathered was analyzed using descriptive statistics. The focus of the analysis was to determine the concepts in chemistry that the students may have not learned well in high school chemistry. A comparison on mean scores was made based on gender and type of school graduated from using t-test of independent samples. The researcher considers these comparisons to establish whether there is a need to vary chemistry instruction according to gender and type of school graduated from. This information is valuable as an input for college chemistry teacher in lesson planning and in choosing appropriate classroom activities to help improve students' understanding of chemistry concepts and correct alternate conceptions.

3. Results and Discussion

Table 1 shows the mean scores and the standard deviation of the performance in the Chemical Concepts Inventory of the incoming freshmen students when grouped according to gender and type of high school graduated from. Results indicated that the students performed poorly in the chemical concepts inventory test. This could mean that the concepts covered in the CCI were not fully mastered by the students.

Table 1. Mean and Standard Deviation in CCI by Gender and Type of School

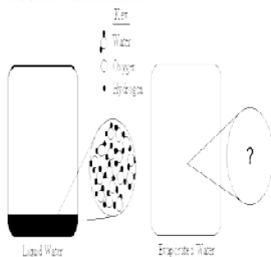
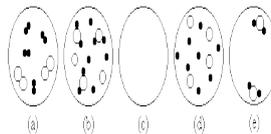
Groups	Mean	Standard Deviation	N (%)
Female	4.63	1.99	273 (54%)
Male	4.75	2.08	229 (46%)
Private	4.64	1.85	116 (23%)
Public	4.69	2.08	386 (77%)

Table 2 shows that the students scored poorly in most conceptual questions with less than 40% of the students getting the correct answer on items covering concepts on chemical reactions, conservation of matter, phases of matter, and properties of matter. These topics are also covered in the general chemistry course in college providing the college chemistry teachers the chance to plan the lessons carefully to address students' difficulty in understanding the concepts. Since chemistry's microscopic aspect is the source of difficulty, pictures or PowerPoint slides of chemical reactions may be presented to show students how atoms are re-arranged during chemical reactions to put emphasis on Law of Conservation of Matter. A clear distinction can also be made regarding the phase changes that water undergoes

so that students will not assume that chemical bonds are broken when water changes from liquid to gas. The lack of fundamental understanding of chemical bonding among high school students around the world can be attributed to the traditional pedagogical approach for teaching chemical bonding that is often overly simplistic and not aligned with the most up-to-date scientific models [7].

Items 2 and 4 which are presented in Table 2 are the items that the students sampled in the study of reference 4 found difficult to answer correctly. This means that these concepts on phase change and chemical bonds are confusing the students and these are good topics for science teachers to focus for planning an intervention to remove alternate conceptions.

Table 2. Selected Conceptual Questions and Students' Responses

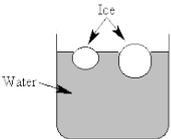
Questions	Responses				
	a %	b %	c %	d %	e %
Which of the following must be the same before and after a chemical reaction? a) The sum of the masses of all substances involved. b) The number of molecules of all substances involved. c) The number of atoms of each type involved. d) Both (a) and (c) must be the same. e) Each of the answers (a), (b), and (c) must be the same.	19	17	10	23*	31
Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water? a) Air b) Oxygen gas and hydrogen gas c) Oxygen d) Water vapor e) Heat	8	29	6	40*	17
What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water? a) 19 Pounds b) 20 Pounds c) Between 20 and 21 pounds d) 21 pounds e) More than 21 pounds	11	19	32	24*	14
The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.  What would the magnified view show after the water evaporates? 	12	20	31	29	8*
Following is a list of properties of a sample of solid sulfur: i. Brittle, crystalline solid. ii. Melting point of 113°C. iii. Density of 2.1 g/cm ³ . iv. Combines with oxygen to form sulfur dioxide Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample? a) i and ii only. b) iii and iv only. c) iv only. d) All of these properties would be the same. e) None of these properties would be the same.	17	21	20*	34	8

*correct answer

Table 3 shows that less than 50% of the sampled incoming first year students were not able to answer the questions correctly on two-tiered items. These items required the students to choose the reason for their answer in the first item. The results indicated that students lacked conceptual understanding. This can be due to the presence of alternate conceptions held by the students [4]. Moreover, these alternate conceptions play a larger role in learning chemistry than simply producing inadequate

explanations to questions. This is because students either consciously or subconsciously construct their concepts as explanations for the behavior, properties, or theories they experience. The students have the tendency to believe most of these explanations are correct because these explanations make sense in terms of their understanding of the behavior of the world around them. College chemistry teachers can design an appropriate teaching intervention to address this problem.

Table 3. Percentage Correct in the Selected Two-tiered Items

Questions	Responses				
	a %	b %	c %	d %	e %
True or False? When a match burns, some matter is destroyed. a) True b) False	69	31*			
What is the reason for your answer to question 1? a) This chemical reaction destroys matter. b) Matter is consumed by the flame. c) The mass of ash is less than the match it came from. d) The atoms are not destroyed, they are only rearranged. e) The match weighs less after burning.	24	28	13	23*	12
Two ice cubes are floating in water:  After the ice melts, will the water level be: a) higher? b) lower? c) the same?	71	9	20*		
What is the reason for your answer to question 3? a) <u>The weight of water displaced is equal to the weight of the ice.</u> b) Water is more dense in its solid form (ice). c) Water molecules displace more volume than ice molecules. d) The water from the ice melting changes the water level. e) When ice melts, its molecules expand.	18*	8	7	45	22
A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.  The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be: a) less than 26.0 grams b) 26.0 grams c) 27.0 grams d) 28.0 grams e) more than 28.0 grams	37	22	19*	10	12
What is the reason for your answer to question 4? A gas weighs less than a solid. Mass is conserved. Iodine gas is less dense than solid iodine. Gases rise. Iodine gas is lighter than air.	28	21*	30	13	8
100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C? a) The water. b) The alcohol. c) Both received the same amount of heat. d) It is impossible to tell from the information given.	24*	36	31	7	2
What is the reason for your answer to question 6? Water has a higher boiling point than the alcohol. <u>Water takes longer to change its temperature than the alcohol.</u> Both increased their temperatures 25°C. Alcohol has a lower density and vapor pressure. Alcohol has a higher specific heat so it heats faster.	25	28*	17	8	22

*correct answer

Students who do not possess appropriate knowledge of mathematics and language for success in chemistry and those who do not have the requisite reasoning skills or both are considered at-risk students [8]. It is recommended that the abstract topics in chemistry be presented only after concrete foundation or conceptual understanding has been attained. Animations, simulations, computer assisted instruction should supplement lectures to scaffold students with low formal thought ability. Moreover, chemistry instructors should pay extra care to the sequencing of concepts and to couple the problem solving activities with conceptual instruction sufficient to explain the how and why. Techniques that overtly confront alternate conceptions or act as discrepant events include the use of multiple representations, discussion of demonstrations, group discussions, cooperative learning, use of concept maps or Venn-diagrams, and guided inquiry are recommended [4]. Addressing alternate conceptions help students understand the concepts correctly and students who developed conceptual understanding can solve chemistry problems with ease.

4. Conclusion and Recommendation

The results of this survey indicated that students need help in developing conceptual understanding on the basic principles and concepts in general chemistry. The college chemistry teacher may focus on attaining mastery on these concepts in the hope of producing more scientifically literate students. Scientific literacy has many context and science teachers are tasked to decide wisely on how to go about attaining the goals of scientific literacy. The teaching of science content should be made meaningful and relevant to students [9]. In addition, it should be taught in a way that students are able to comprehend and appreciate it. He warns that unless science teachers do this, science is another lifeless abstraction. These findings can be good starting points for research on designing

intervention and instructional materials to correct alternate conceptions on specific topics or concepts and improve students' achievement in chemistry. Although this problem in chemistry achievement is long standing, more researches on teaching intervention are still needed to improve students' conceptual understanding in chemistry. More research may be conducted to address the learning difficulty encountered by the students in these topics.

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