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An Old Subject with Recent Evidence from Turkey: Students' Performance on Algorithmic and Conceptual Questions of Chemistry

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Abstract: This study has been designed to investigate students' understanding of algorithmic and conceptual questions of chemistry concepts. Although it has been worked on the topic since 1980s, this study targets to renew and remind the old experience which is actually a recent important problem in the developing world. A total of 199 eleventh grade students from Ankara (Turkey) participated in the study. Four tests with different subjects had been utilized; (1). Structure of atom and periodical table, (2) the concept of mole, (3) gas laws and (4) solutions. Each test consisted of 40 items and 5 multiple choice alternatives for the answers. Items, on the other hand, were made up of 20 conceptual and 20 algorithmic problems. Tests were developed by the researchers of the current study. Unlike the general tendency investigated by many of the researchers that, students displayed high performance in solving algorithmic problems and low performance for the conceptual cases, students of this study revealed high performance in both areas. Resulted high performance was attributed to adequacy of high school chemistry education in Turkey system and also to the special situation of the 11th grade students in Turkey that they have to take University Selection Exam to attend a university and they are in the stage of preparing for the exam beginning from 10th, even 9th grades. Therefore, the results may not reflect students' high performance in chemistry but that of their ability for problem solving for just finding the answer in the university entrance exam.

Key words: Algorithmic questions · conceptual questions · chemistry concepts

INTRODUCTION

Science teaching has focused on achieving two major goals; developing sound understandings of the main science concepts and acquiring skills in problem solving on a particular domain. An important goal of chemistry education is to help students to develop their understanding of the concepts and use them for solving problems. There are several definitions of problem solving. According to Wheatley [1], for example, problem solving is '*what you do when you don't know what to do*'. [2], on the other hand, defined problem solving as a result of the application of knowledge and procedures to a perceived problem. And it was defined by Ausubel *et al*, [3] as a form of meaningful discovery learning, but not a completely autonomous discovery, they insisted that no frequently practiced procedure or strategy could be called problem solving. Moreover, as also emphasized by Chiu [4], many students adept at solving problems with algebraic equations, but had only limited understanding of the chemistry behind their algorithmic manipulations. According to Reid and Young [5], the reason for the gap between conceptual understanding and algorithmic problem solving in chemistry students from high school to graduate school might be conventional teaching techniques that tend to focus on correct numerical answers. There are other studies, however, proposing insights on the question. Zoller [6], for example, concluded as a result of his study with the university students in Israel that, traditional strategies of teaching and assessment in chemistry are not compatible with the development and fostering of students' high order cognitive skills. Therefore, he declared that he supports the effort being made

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worldwide, to implement HOCS-oriented teaching strategies and conceptual teaching pedagogies in science classrooms. In any circumstances, however, in order to succeed academically, high school students should be capable in solving both algorithmic and conceptual problems. Algorithmic problem solving strategies require the application and manipulation of certain mathematical formulas whereas; conceptual problem solving requires sound understanding of science concepts and the application of conceptual knowledge. Although conceptual understanding is identified as a major goal of science teaching, instruction in chemistry courses usually stress complex processes to solve algorithmic problems. Science teachers have often assumed that students' performance in mathematical problem solving should indicate mastery of a chemical concept [7]. However, as stated by Nurrenbern and Pickering [8], Nakhleh [9] and Nakhleh, and Mitchell [10], students' ability in solving algorithmic problems on gas laws and stoichiometry have little connection to their understanding of the related concepts. Hence, it can be concluded as a result of the above studies that, in general, students can solve algorithmically-based problems but can not use chemical concepts to solve conceptual problems. The literature contains evidences that, novice problem solvers in chemistry usually have greater success with solving problems of an algorithmic mode than problems having a more conceptual base [9,11,12]. Student training in algorithmic-mode problems did not guarantee successful understanding of conceptual problems. "Algorithmic and conceptual problems may require different cognitive abilities [13]. The results of the study conducted by Niaz [14] indicated the considerable difference in students' performance on conceptual and algorithmic problems concerning mole, gases, solutions and photoelectric effect. According to this study, the ability to solve algorithmic problems does not lead to conceptual understanding. As a result of their study about determining university students' level for solving paired algorithmic and conceptual problems about density, stoichiometry, bonding and gas laws, Mason, *et al.* [15] concluded that, 65 % of the students displayed great ability to solve algorithmic problems correctly, but failed in conceptual problems. Furthermore, BouJaoude *et al.* [7] reported that high school students' conceptual understanding on gas laws, chemical change, limiting reagents and chemical equations were not highly connected to their ability to solve algorithmic problems, because students' performance was found to be significantly better on algorithmic problems than that on conceptual problems. Chiu [4] studying on several test topics as gas laws, equations, limiting reagents, empirical formulas, density and acid-base titration, indicated that students did better in solving algorithmic problems than they did in conceptual questions. However, inconsistent with other studies in this field, the results of Chiu's research revealed that many students were both good problem solvers and good conceptual thinkers. The reason for bringing this so called "*old*" subject into the agenda is that, there is no such study in Turkey to find out students' performance on algorithmic and conceptual problems. Moreover, the renewals in the chemistry education system need to be constructed upon such facts. As far as the international value of the study is

Table 1: Content of the tests

Test Subject	Concepts covered	Reliability*
Atomic structure and the Periodical Table	· subatomic particles(electron, proton and neutron)	
	· electron configuration	
	· relation between protons and electrons in the charged atoms	
	· general features of the periodical table	0.80
Mole	· mass-molecular weight	
	· number of molecules	
	· number of atoms in a molecule	
	· avagadro number	
	· volume -number of molecules	0.74
Gas law	· irregular structure of gases	
	· relation of pressure with number of molecules and temperature and volume	0.84
Solutions	· nature of solution, solubility	
	· effect of temperature and pressure on solubility	
	· concentration of solutions	
	· relation between dilution and boiling point in the concept of solutions	0.79

* Reliability of the tests were found by calculating internal consistency values using Cronbach's alpha.

concerned, on the other hand, it helps to renovate the trends in chemistry teaching and proposes a case from the current agenda of the developing country. Therefore, this study has been designed to investigate Turkish students' understanding of chemistry concepts, which will provide valuable information for achieving science teaching goals.

Research Question: In this respect, the present study aims to (1) determine Turkish high school students' performance on conceptual and algorithmic chemistry problems, (2) Examine the differences in abilities to solve algorithmic and conceptual questions. (3) Evaluate the results in relation with recent applications in Turkey.

MATERIALS AND METHODS

***Sample*:** A total of 199 eleventh grade students from 2 high schools in Ankara (Turkey) participated in this study. There were 76 girls and 123 boys with an average age of 17.7.

***Instrument*:** Four tests with different subjects had been utilized during the study; (1) Atomic structure and periodical table, (2) the concept of mole, (3) gas laws and (4) solutions. Each test consisted of 40 items and 5 multiple choice alternatives for the answers. Items, on the other hand, were made up of 20 conceptual and 20 algorithmic problems. Tests were developed by the researchers of the current study. Four experts in the field of chemistry education examined an initial version of the tests according to the following factors: (a) the adequacy of the chemistry content covered in the test with respect to its appropriateness with Turkish curriculum and (b) suitability of the distracters. The content of the resulted tests was as follows:

Procedure: The authors visited the schools after getting permission from the administration. Students were told about the purpose of the test and the procedure for completing the scales. Students were informed about the object and content of the test. They were asked to answer the questions on their own and to think about each question and answer it as it applied to them. It took about 50 minutes for the students to complete the test.

***Statistical Analysis*:** Statistical Package for the Social Sciences (SPSS, version 11.0) had been utilized to perform the statistical analysis. Descriptive statistics were used to assess participants' abilities in solving algorithmically-based and conceptual problems on the related chemistry topics. Differences in students' abilities for solving algorithmic and conceptual problems, on the other hand, had been realized by means of comparing the mean scores using paired samples t-test analysis.

RESULTS

Students' performance: Students' answers were evaluated based on the conceptual understanding and algorithmic problem solving skills under the 4 categories of the questions. The categories are as follows:

HAHC: High achievement on both algorithmic and conceptual problems.

HALC: High achievement on algorithmic problems but, low achievement on conceptual problems.

LAHC: Low achievement on algorithmic problems but, high achievement on conceptual problems.

LALC: Low achievement on algorithmic problems but, low achievement on conceptual problems.

High and low levels of achievements, on the other hand, were determined based on the scores. Students, who got over 50% of the total, were categorized as a high performer (H) in that category. For the scores of 50% or less, they were categorized as a low performer (L). Results are presented according to four types of tests in Figure 1 below.

According to the results presented in Figure 1, 75.8%, 70.4%, 79.2% and 86.9% of the students

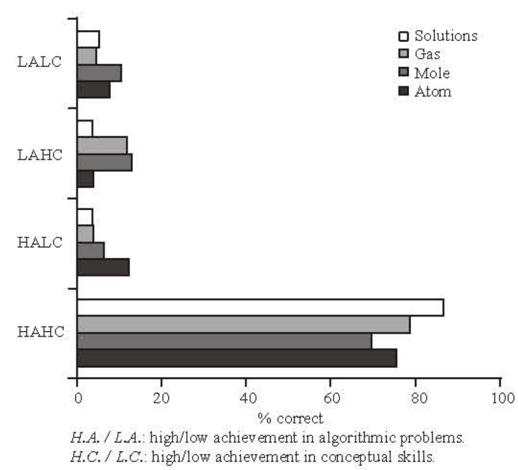


Fig. 1: Comparison of Students' Algorithmic vs. Conceptual Problem Solving Abilities

Table 2: Basic Descriptive Statistics on Algorithmic and Conceptual Problems

	Mean	Std. Dev.	t value
ATOM			-10.03
Algorithmic	15.4	3.4	
Conceptual	13.6	3.9	
MOLE			3.56
Algorithmic	13.7	4.3	
Conceptual	14.4	3.5	
GAS LAWS			7.65
Algorithmic	13.4	3.6	
Conceptual	15.7	3.4	
SOLUTIONS			7.64
Algorithmic	15.6	3.6	
Conceptual	14.7	2.9	

*significant level $p<0.05$.

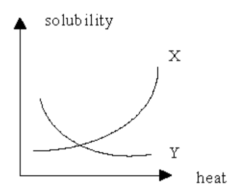
displayed high achievement in both algorithmic and conceptual questions for all the tests related with atom-periodical table, mol, gases and solutions, respectively. 13 % of the students' answers were evaluated as low, in algorithmic problems for the concept of moles and about 12 % of the students' performance was evaluated as low in algorithmic problems for gases.

Relation between algorithmic and conceptual problems: The mean total scores (M), standard deviations (SD) and paired sample t-test results on algorithmic and conceptual problems concerning the 4 tests (atom- periodical table, mole, gas laws and solutions) are presented in Table 2. The results showed that the difference in students' performance between algorithmic and conceptual problems was statistically significant for the tests dealing with the mole and gas laws: Students' performance was higher in conceptual problems than algorithmic problems. For the concept of atom- periodical table and solutions, on the other hand, students' performance was significantly better on algorithmic problems compared with the conceptual problems.

Example questions for 4 topics, considering the content have been given in Table 3. In one of the algorithmic questions for the atomic structure and periodical table concepts, for example, students were tested for their algorithmic performance about the relation between number of protons and atomic charge. Students were expected to be aware of that, proton numbers are equal to that of electrons in the atoms in neutral state and (+)ly charged ions of an atom has more protons. Percentage of students who gave the right answer was found as 65. revealing that the rest of the students can not make a relation between the concepts of atomic numbers and atomic charges. The question that tests students' conceptual understanding of the same subject, on the other hand, was related with atomic number of a X^{+4} charged atom. Students were expected to know that the atomic number equals number of protons and number of protons can be found by adding 4 to the number of electrons, since it is +4 charged. Percentage of students who give the right answer is about 70. The major mistake for this question seemed to be resulted by means of the misuse of the relation; atomic number = mass number – number of neutrons. It was not possible to use this relation, because, although mass number had been given, there wasn't any information about number of neutrons. Another reason for the students giving wrong answer to this question was that, they have an idea that atomic number can be calculated by means of valence electrons. Choices given for this question, on the other hand, also test conceptual understanding of the students: for the first choice, students were expected to know that, it was not possible to calculate atomic number by just knowing the mass number, since mass number is the total number of protons and electrons of an atom and at the same time, the number of protons equals the atomic number. Second choice was not possible either for the students who knew that, atomic number of X^{+4} charged atom can be found by adding 4 to its number of electrons. Moreover, in order to eliminate the third choice, they had to know that, number of valence electrons does not give any information about the atomic number, but points out the group that the atom belongs in the periodical table.

Algorithmic type of question for "mole" concept requires students to know that, it is necessary to multiply number of moles and atoms of that substance in order to find out the number of atoms in a molecule. By the way, in order to answer this question student should also know that, at standard conditions, it is enough to compare volumes of gases to compare their number of molecules. Therefore, the right answer is "d" and the percent of students who answered this question by the use of this information is 72.4. The question that tests students' conceptual performance on the same subject deals with the Avogadro's principle. Students are expected to use their knowledge about this principle that, equal volumes of all gases at the same temperature and pressure contain the same number of molecules. Seventy three percent of the students choose the right answer, but most of the students answered the question wrongly because, they made a mistake by thinking that the gases with the same volumes are the same. When the options for this

Table 3: Algorithmic and Conceptual questions for the four topics of the study

Topic	Algorithmic	Conceptual understanding
Atomic structure and periodical table	$_{24}X^{+3}$ ve Y^{+1} have equal number of electrons. What is the atomic number of Y atom? a) 27 b)* 22 c) 20 d) 21 e) 24	Which one/s should be given among the below given features, in order to find out the atomic number of the X^{+4} ion? I. mass number II. number of electrons III. valence electrons of atom X a)* only I b) only II c) only III d) I- II e) I, II, III
Mole	Which one of the followings contains equal number of atoms with 8 g oxygen? a) 0.5 mole N_2 gas b) 11.2 liters CO gas at STP c) 1.2 g C d)* 5.6 liters Cl_2 gas at STP e) 4 g He gas	Which one of the followings is true for X and Y gases which comprise the volumes at the standard conditions? a) they have equal an mass b) they have equal molecular weights c) they are the same gases d) they contain equal number of atoms e) *they contain equal number of molecules
gas law	What is the pressure (atm) resulted from 22 g CO_2 gas in a 16.4 liter container at 127°C ?a) 4 b) 3 c) 2 d)* 1 e) 0.5	Pressure of an ideal gas in a container depends certainly on; I. temperature of the container II. density of the gas III. number of atoms in a molecule a)* only I b) I- II c) II- III d) I,II, III e) only II
solubility	200 g of sugar solution by 20% mass is saturated at t°C. What is the solubility of sugar, as g/100ml water, at this temperature? a) 15 b)* 25 c) 30 d)35 e) 40	 Solubility graphs of X and Y are given in the above graph. Which one of the followings is wrong, according to the graph?a) *Solubility of X is endothermic. b) Solution gets warmer as Y gates soluble in the water. c) Both, X&Y might be a solid matter. d) Y may be a gas. e) Precipitation will result, if the saturated X solutions are cooled down.

question are evaluated, on the other hand, it has been seen that, students thinking that the ratio of volumes are the same as the ratio of masses, choose option “a” (3%). The ones, who thought that gases with the equal volumes have the same molecular weights, choose option “b” (6 %). Option “c” had been chosen by the students (%2.5), who thought that, two gases are the same if they have same volumes at the same conditions. Lastly, 12.1 % of the students choose another wrong option “d”, thinking that, there is a direct relationship between volume and number of atoms.

Students were expected to interpret the equation; P=NRT/V, for the algorithmic type of question for “gas law”. Percentage of students that was satisfied was 86.9. Pressure of a gas depends on its number of molecules, its temperature and the volume of the container. Accordingly, among the options given, pressure depends only on I. Therefore, the students who know the factors that the pressure of a gas depends on and who can comment on the ideal gas law given choose the right option.

Conceptual type of question for the same subject depends on information that pressure of gases changes with temperature, number of molecules of the gas and the volume of the container. Percent of student giving the right answer to this question is just 51.3. The reasons for the low percentage of the right answers, on the other hand, are related to the fact that some of the students made a correlation between high gas pressure-and- high density and some of them made a correlation between number of atoms in the gas molecule – and – gas pressure, which is not true.

Percent of right answers for both algorithmic and conceptual type of "solubility" questions were higher than 80 for most of the cases. One of the examples for the algorithmic type of solubility questions was about the solubility of sugar in water (Table 3). Students were expected to calculate the amounts of sugar and water in 200 g of 20% sugar-water solution. The ones who found out that the amount of water in such a solution is 160 g and that of sugar is 40 g ended up with the correct answer. Eighty two percent of the students gave the correct answer. The students who thought that there exists 20 g of sugar in 200 g of solution, on the other hand, failed to give the correct answer.

For the conceptual type of question about "solubility", students had to know that, as temperature increases the solubility of solids increases and that of gases decreases in general, but there are several exceptional cases. Therefore, students who thought that solid matter precipitates whenever a solution is cooled down, failed to choose the correct answer. Percent of students thought so, on the other hand, was only 13, the rest is seemed to be aware of the concept. Therefore, 82.9% of the students participated in this study are capable of making meaningful comments on the graph given and they know that; solubility reaction with increasing solubility by increasing temperature is endothermic (option "a"); that, solubility reaction of a solid matter with decreasing solubility by increasing temperature is exothermic; solubility reaction of X in water is an endothermic, that of Y, on the other hand is an exothermic. Therefore, students who knew the above mentioned concepts concluded that, as Y becomes soluble in water, water gets warmer (option b is true), X is certainly a solid matter (option "c" is true), Y might be a gas or a solid matter (option "d" is true) and when solution Y is cooled down there will be no precipitation, because as temperature decreases, the solubility of Y will increase (option "e" wrong).

DISCUSSION AND CONCLUSIONS

High school students' performance on conceptual and algorithmic chemistry problems has been evaluated in this study, based on the results of 4 tests applied to 199 11th grade students. Unlike the general tendency investigated by many of the researchers [9, 10], that students display high performance in solving algorithmic problems and low performance for the conceptual cases, students of this study revealed high performance in both areas. This finding, on the other hand, is consisted with the results of the study realized by Chiu [4] about algorithmic problems solving and conceptual understanding of high school students in Taiwan. Chiu defined students in his study as good problem solvers and good conceptual thinkers. But, as also mentioned by Chiu, although the findings of both studies are quite promising, this sample of students is not representative of all high school students in Turkey or in Taiwan. We still have a considerable number of students who may not acquire the desired knowledge of chemistry concepts and mathematical skills that are needed for learning specific topics in chemistry.

Although the resulted high performance of Turkish students of this study may imply that, high school chemistry education in Turkey system provides an adequate understanding of chemical concepts, this result can also be attributed to the special situation of the 11th grade students in Turkey: 11th grade students has to take University Selection Exam to attend university and they are in the stage of preparing for the exam beginning from 10th, even 9th grades. Therefore, they have being developed necessary strategies in different types of problems may explain the high performance resulted in this study. Moreover, it is a well known fact that, most of the chemistry questions in such exams are, related to atomic structure, periodical table, mole, gas and solutions and therefore, while preparing for the exams, students concentrate especially on these concepts. Therefore, as also emphasized by Nakhleh and Mitchell [10], this work may suggest that, our current methods of teaching chemistry in Turkey, especially for the students preparing for the university entrance exams, are, perhaps, not teaching chemistry, but teaching how to get answers to selected algorithmic and conceptual problems. The reason for the high performance of students is especially related with their special situation, on the other hand, is that, implying an adequate system for chemistry concepts in Turkey does not reflect the truth. Explanation for this observation can be made by giving details about the system applied in Turkey. Traditional teaching methods are being used in Turkish schools; teachers of both primary and secondary schools use presentation method, laboratories are not used as primary learning centers of science and they prefer demonstration and deduction methods while implementing their laboratory activities [16]. But, whatever the reason is, it seems that Turkish students at this level of schooling are trained in order to master in conceptual problem solving skills for some chemistry topics. However, students had obtained significantly higher mean scores on algorithmic problems on certain chemistry topics, since application and manipulation of mathematical formulas are practiced extensively during instruction to meet the requirements of the university selection exams. But still, as mentioned by Zoller [6], if we wish to endow our students with more than just algorithmic capabilities, more HOCS (higher-order cognitive skills) oriented curricula, teaching materials, teaching strategies as well as adequate assessment tools are to be developed and implemented. Such an action has the chance of developing the students' reasoning and critical thinking ability in the context of both specific and general science content and STES interfaces, as well as their problem-solving, decision-making capacity so they can be effective citizens.

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