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Nejla Gultepe
Süleyman Demirel High School, Turkey, nejlagultepe@gmail.com

Ayse Yalcin Celik
Gazi University, Turkey, ayseyalcin@gazi.edu.tr

Ziya Kilic
Gazi University, Turkey, zkilic@gazi.edu.tr

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Exploring Effects of High School Students' Mathematical Processing Skills and Conceptual Understanding of Chemical Concepts on Algorithmic Problem Solving

Nejla Gultepe
Suleyman Demirel High School, Turkey
Ayse Yalcin Celik
Ziya Kilic
Gazi University, Turkey

Abstract: The purpose of the study was to examine the effects of students' conceptual understanding of chemical concepts and mathematical processing skills on algorithmic problem-solving skills. The sample (N = 554) included grades 9, 10, and 11 students in Turkey. Data were collected using the instrument "MPC Test" and with interviews. The MPC Test consists of 3 sections: 8 conceptual questions (Qcu), 8 algorithmic problems (Qcc), 8 mathematics questions (Qm). It was concluded that students' conceptual understanding and mathematical processing skills effected algorithmic problem-solving skills. The effects of conceptual understanding were much more than mathematical processing skills on algorithmic problem-solving skills. According to the MCT Test results, 10 students with high, average, and low grades were interviewed. Qualitative findings were consistent with quantitative results. There is a significant relationship between students' algorithmic skills and their mathematical skills. Also, it was concluded that students' conceptual understandings are effective on solving chemistry problems but solving chemistry problems correctly does not mean chemistry concepts can be understood truly and deeply on a molecular level.

Introduction

In recent decades, a large amount of research in science education has investigated students' ideas about all chemistry topics from basic chemical concepts (e.g., the elementary entities of matter, chemical equilibrium, mole, etc.) to conceptual change (e.g., chemical change, conservation of mass, acids and bases, solutions and solubility equilibrium, etc.), conceptual framework (e.g., enzymes, etc.), and problem-solving skills (e.g., chemical equilibrium, acids and bases, gases and chemical reactions, etc.) (Cakir, Uzuntiryaki, & Geban, 2002; Camacho & Good, 1989; Chiu, 2001; Krajcik, 1991; Nakhleh, 1992; Sutcliffe & Scrutton, 2002). The common purpose of these studies is to determine the barriers that students encounter while learning chemical knowledge so as to make chemistry teaching more effective.

It is generally accepted that learning chemistry is difficult for many students (Nakhleh, 1992). There are many factors that hinder students' learning chemistry, such as inadequate algorithmic skills, the hierarchical structure of concepts, textbooks, and instructional methods. In all countries, problem solving is the main part of chemistry education. Most chemistry teachers believe that problem solving leads to understanding chemistry. Although enhancing students' problem-solving ability is a main goal of chemistry teaching, it is well known that problem solving is the most difficult part for many chemistry students (Bowen & Bunce, 1997).

Some very important assessments have shown that there is a considerable gap between students' ability to solve algorithmic questions (symbolic or numerical) that can be answered by applying a set procedure to generate a response (Bowen & Bunce, 1997) and their comprehension of chemical concepts (Boujaoude & Barakat, 2000; Cracolice, Deming, & Ehlert, 2008; Nakhleh, 1993; Niaz, 1995a, 1995b, 2005; Pickering, 1990; Stamovlasis, Tsaparlis, Kamilatos, Papaoikonomou, & Zarotiadou, 2004, 2005). Educating students in algorithmic-mode problems does not guarantee successful understanding of conceptual problems. Niaz (1995a) found a considerable difference in students' performance on conceptual and algorithmic problems concerning mole, gases, solutions, and photoelectric effects.

Many students solve chemistry problems using algorithmic strategies and do not understand the chemical concepts behind their algorithmic manipulations; they have less trouble with the algorithmic part of the problem than they do with the conceptual part (Cracolice et al., 2008). Identifying this concern is problematic because teachers may accept a correct numerical answer without examining students' conceptual understanding dealing with the related concepts (Dahsah & Coll, 2007, 2008; Nakhleh, 1993; Nakhleh & Mitchell, 1993). If this occurs, then students who produce the correct numerical answer may be presumed to have an understanding of the underlying concepts (Sawrey, 1990). Teachers find it easier to teach algorithms and formulas, neglecting the conceptual knowledge, or they encourage students to enhance their problem-solving or algorithmic skills (Gabel & Bunce, 1994; Kean, Hurt Middlecamp, & Scott, 1988). For example, students may be capable of solving problems that involve using equations to predict the properties of gases under a variety of conditions; however, their conceptual understanding falls behind this *algorithmic* understanding (Nakhleh, 1992; Niaz & Robinson, 1992; Russell et al., 1997). Students' levels of conceptual understanding have a significant effect on their ability to identify examples more quickly and clearly and to solve problems by understanding them (Camacho & Good, 1989: Nurrenbern & Pickering, 1987). It is vital that students comprehend the particular nature of matter, in its own nature of chemistry, according to the scientific point of view because then they can comprehend other concepts about the structure of matter (Gabel, Samuel, & Hunn, 1987; Krajcik, 1991; Nakhleh, 1992) and will be able to solve new or uncommon problems (Krajcik, 1991; Nakhleh, 1992); otherwise, they will have to resort to rote learning of definitions, formulae, and processes (Stefani & Tsaparlis, 2008). Nurrenbern and Pickering (1987) stated that students do not struggle to understand chemical equations on a molecular level. Yarroch (1985) found that students make fewer mistakes when they balance reactions but they are inadequate at drawing the microrepresentations of chemical reactions and do not understand the formulas in reactions and coefficients. Similarly, Krajcik (1991) and Gültepe (2004) found that students solve algorithmic chemical problems using formulas as if doing a puzzle and they express them in a comfortable way. However, in light of the interviews in Gültepe's (2004) study, students cannot explain the physical and chemical phenomena (e.g., dissolution, metallic corrosion, and carbon dioxide formation) and cannot clearly describe the interactions taking place at the molecular level. Gültepe (2004) linked these findings to students' not comprehending the concepts at the molecular level and not reconciling the relations between concepts and agreed with the view of Niaz (1995a) that students with strong conceptual knowledge are better at algorithmic problem solving.

Teachers are limited by curriculum with respect to encouraging conceptual thinking. They assess students' chemistry knowledge by problems in which utilization of formulas are needed to get the numerical value (Gabel & Bunce, 1994; Hurt Middlecamp & Kean, 1987; Kean et al., 1988). These researchers have shown that, for some problems, teachers find it easier to teach them with algorithm and formulas and neglect the conceptual knowledge or that they encourage students to enhance their problem-solving or algebraic skills. Gulacar and Fenewever (2010) noted that students whose knowledge is context dependent could not solve problems that require deep connections in their cognitive structure. The concepts and issues that need attention require the employment of higher-order cognitive skills (HOCS; Papaphotis & Tsaparlis, 2008*;* Tsaparlis & Zoller, 2003; Zoller, Lubezky, Nakhleh, Tessier, & Dori, 1995). According to Zoller and Tsaparlis (1997), HOCS items include “quantitative problems or conceptual questions unfamiliar to the student, that require more than knowledge and application of known algorithms for their solutions, require analysis and synthesis procedure, problem solving capabilities, making connections and critical evaluative thinking” (p. 118).

Various studies have identified students who can qualitatively explain but cannot calculate well (Gültepe, 2004; Pushkin, 1998). These students have adequate conceptual knowledge but inadequate mathematical processing skills to solve problems. While they also have difficulty in using formulas, their performance on conceptual questions is better than on algorithmic questions. Tobias (1990) named them *second-tier* students. In addition, some students can calculate algorithmic questions without the slightest clue as to why they are doing so, and some students can calculate and explain. Chiu (2001) and Nakhleh (1993) named this latter group as *both highly algorithmic with highly conceptual* (HAHC – a group with high performance on algorithmic problems, high performance on conceptual questions). They are able to perceive the chemical conceptions of problems at macroscopic and microscopic levels, apply mathematical processing skills well to the solution of the problems, make detailed diagrams and symbols related to the chemical reactions in the problem, and think about concepts in terms of mathematical relations.

The goal of good chemical education is to build up an equally strong conceptual and algorithmic understanding and then to reinforce their interdependence. These various aspects with respect to student learning are an important and timely issue across all areas of science education (Raizen, 1997). In this study, we explored the question: Is mathematical processing skills and/or conceptual understanding more effective for solving algorithmic problems? Knowing the answer to this question will support teachers in both knowing where to focus their teaching and how to assess students’ work better.

Purpose of The Research

The studies mentioned above basically indicate that students being able to solve algorithmic problems about chemistry does not necessarily mean that they have the conceptual understanding adequate for the scientific view about that issue. Setting out from this, the notions that *Students who solve algorithmic problems do not have comprehended that topic* and that *Students with conceptual understanding adequate for the scientific view can solve algorithmic problems* can be assumed. To make this situation possible, students must have the required mathematical skills; therefore, an explication about whether a student with adequate conceptual understanding and mathematical processing skills is able to solve an algorithmic question can be made. This study aimed to identify the effects of students’ understanding of chemical concepts and of their mathematical processing skills on their algorithmic problem-solving skills.

Research Questions

The following research questions were investigated in the study:

1. Is there a statistically significant relation between mathematical processing skills and/or conceptual understanding and algorithmic problem-solving skills?
2. To what degree do mathematical processing skills and conceptual knowledge have an effect on students' algorithmic problem-solving skills?
3. Can conceptual understanding test results and mathematical processing skills be used to predict students' algorithmic problem-solving skills?

Methodology

Data Analysis

We adopted a mixed-method approach through the use of test scores and interviews to explore at a deeper level the knowledge of different kinds of students. A correlational analysis and a regression analysis as a quantitative technique were employed, pursuing the goal of the relationship between high school students' mathematical processing skills, algorithmic problem-solving skills, and conceptual understanding. As well, we have qualitative data in the form of semistructured interviews.

Participants

The study was conducted at 10 high schools in Turkey; all were in the same geographic region. In Turkey, there are three types of schools that are categorized by students' scores on the national High School Entrance Examination, which is given at the end of elementary education (average age of students 15-17 years old). Of the 10 schools, 2 were science high schools whose students have higher thinking capability as assessed by high scores on the examination, 5 were Anatolian high schools whose students achieved average scores, and 3 were high schools that accept students who failed the examination. Of the 554 students participating in the study, 118 were in Grade 9, 204 were in Grade 10, and 232 were in Grade 11. Even if there were students with different levels of high school entries in the research, there were students with these three levels in each grade.

Data Collection

MPC Test

A test was prepared for determining whether students use concepts related to the subject while solving chemistry problems and whether mathematical processing skills affect the solution of algorithmic problems by one of the researchers in the master thesis. The test is called MPC because it contains questions assessing mathematical processing skills (M), algorithmic problem solving (P), and conceptual understanding (C). Conceptual questions are about pure substances, mixtures, gas laws, solutions, chemical calculations, and mole concept. The test contained three types of problems for each concept, which aimed to determine the degree that students can comprehend the concept and can solve algorithmic and mathematical part of the question.

The test consisted of 24 questions in three sections. Section 1 has 8 multiple-choice conceptual questions (Q_{cu}) that assess conceptual understanding of macroscopic and submicroscopic levels of specific subjects; Section 2 has 8 multiple-choice algorithmic problems (Q_{cc}) about these subjects; Section 3 has 8 multiple-choice mathematics questions (Q_m) to determine students' mathematical processing skills which is related to algorithmic problems . Three question types for each subject were jumbled to not give students a pattern with respect to what was being assessed.

Two questions were related to the mole concept to assess algorithmic and conceptual knowledge. Through these questions, the students' mole concept knowledge related to number and mass of atom/molecule was examined. Two conceptual questions about chemical reactions were about the changes of atoms/molecules in chemical reactions, and two algorithmic questions were about forming a compound and a stoichiometry problem. Of the two questions about the ideal gas law, one was conceptual and the other was algorithmic. Of the two questions about solutions, one was was about concentration units and the other examined their knowledge about solubility of salts on a particular level conceptually. Students' concepts about atom, molecule, compound, and mixtures were examined as well as chemical calculations concerning these concepts. The last two questions related to changes in states of matter and a heat transfer calculation.

The reliability of the MPC Test was examined by Cronbach alpha with a result of $(\alpha) = .71$. It was analyzed by 4 science educators and 2 chemistry teachers as fitting the purpose and high in content validity.

In order to assess student performance better and increase the reliability of student answers, for algorithmic questions students were asked to write down all the steps of the solutions, and for conceptual questions students were asked to explain their reasoning. While assessing data, 1 point was given for a correct answer and 0 point was given for an incorrect answer. The highest possible score on each section of the test was 8 and on the whole test was 24. Sample test questions are given below:

Q6.1. Mathematical question (Q_M): A person who has 120.-TL [Turkish currency] wants to buy suits of the same colour from a shop in which a jacket costs 20.-TL and a pair of trousers cost 15.-TL. How many suits can that person buy?

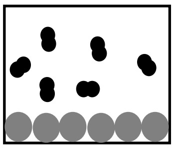
Solution: One suit is 15.-TL + 20.-TL = 35.-TL; 120.-TL/35.-TL = 3.429 suits
Since suits cannot be in decimal numbers, the person buys three suits and 120.-TL - 3x35.-TL = 15.-TL is left.

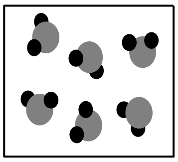
Q6.2. Algorithmic chemistry question (Q_{CC}): Consider the equation for a reaction is $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$. When 1.8 mole oxygen gas (O_2) and 2.0 mole sulphur (S) react on each other, how many grams of sulphur trioxide (SO_3) gas are produced at most? (S = 32g/mole; O = 16g/mole)

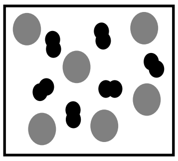
Solution: According to the reaction equation, since 2.0 mole sulphur and 3.0 mole oxygen react on each other, 3.0 mole SO_3 is produced; 1.8 mole O_2 and (1.8/3) x 2 = 1.2 mole sulphur react on each other and 2.0 - 1.2 = 0.8 mole sulphur remains. Since moles are equal, 1.2 mole SO_3 is produced when 1.2 mole sulfur is used; and since molar mass is (32+3x16) = 80 g/mole, 1.2x80 = 96g SO_3 is formed.

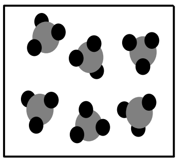
Q6.3. Conceptual question (Q_{CU}): The equation for a reaction is $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$.

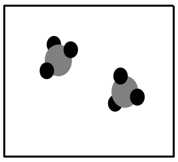
Consider a mixture of S (•) and O_2 (••) in a closed container as illustrated below:
Which of the following represents the product mixture?

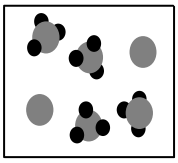












Solution: There are six sulfur atoms and six oxygen molecules in the container initially; after the reaction, four SO_3 molecules should be formed and two sulfur atoms should remain.

While preparing the mathematics questions, their similarity to chemistry problems in terms of logic process or practicing same mathematical operations were carefully considered. For example, in Q6.1 above (how many suits can be created with 120 TL with different prices of pants and jackets), the same logic process is reinforced in Q6.2 (how many grams of compound can be obtained using different amounts of oxygen and sulphur); similarly, Q6.3 aims to evaluate students' comprehension of molecular level.

Interviews

Semistructured interviews were conducted to understand how the students used their previous knowledge for answering the MPC Test questions. The interviewer asked standardized questions and some probing questions to ensure that the participants understood the questions. Also, there was no order in which questions were asked (Harrell & Bradley, 2009). The interview was designed to identify whether their true chemical calculations showed that they had understood the related concepts well and whether their choosing the correct answer showed that they knew why the other choices were wrong. Ten students, at least three from each grade, participated; these students were determined after their test results were classified as either good, average, or weak. Interview questions were designed based on their answers given to conceptual and algorithmic questions applied. During the interview, students' present knowledge about chemical concepts and perception of chemical reactions were probed, using methods such as having them draw and make word associations. Interviews lasted 45-50 minutes. Students orally answered the questions; dialogue notes were made by the researcher during the interview; the notes were transcribed and later analyzed.

Results

Mathematical processing skill (Q_m), algorithmic problem-solving skill (Q_{cc}), and conceptual understanding (Q_{cu}) points of the students in descriptive statistic results according to their grade level are given below (Table 1). It can be seen that Grade 11 students' results on mathematical processing, algorithmic problem-solving skills, and conceptual understanding are generally better than the Grades 9 and 10 students' results. However, the difference between the Grade 9 students' mathematical processing skills ($\overline{X}$= 6.12, SD = 1.47) and the Grade 11 students ($\overline{X}$= 6.12, SD = 1.47) is small. Considering the students' answers for the three question types in the MPC Test, all three grades were most successful in Q_m and least successful in Q_{cu}. This result was anticipated, because the literature reported that students are better in mathematical questions than in conceptual ones. When the students' answers are compared according to grade level, the situation remains the same. Nevertheless, when the three grades are compared within each other, the success level of Grade 11 students is far higher than for the other grades (Figure 1).

Question type	Grade	N	$\bar{X}$	SS
Mathematical calculations (Q_m)	9	118	6.12	1.47
	10	204	5.77	1.95
	11	232	6.31	1.59
	Total	524	6.07	1.72
Algorithmic problem solving (Q_{cc})	9	118	3.54	1.77
	10	204	3.52	2.27
	11	232	4.82	2.32
	Total	554	4.07	2.28
Conceptual understanding (Q_{cu})	9	118	3.07	1.42
	10	204	2.79	1.83
	11	232	4.15	2.13
	Total	554	3.42	1.99

Table 1: Descriptive Statistic Results of Students' Q_{cu}, Q_{cc} & Q_m Points

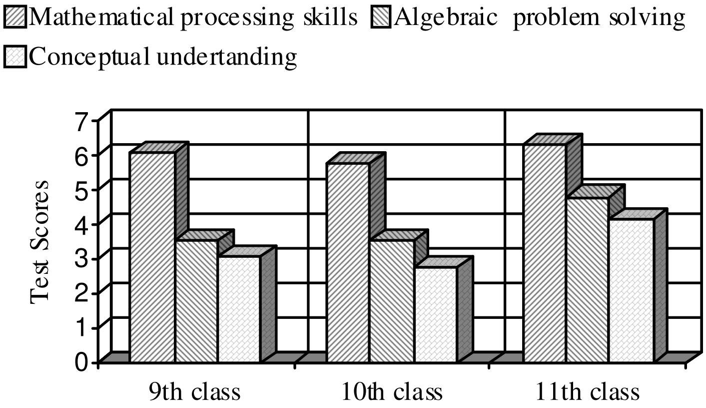


Figure 1. Test scores of MPC.

Relationships of Mathematical Processing Skills, Solving Algorithmic Problems, and Conceptual Understanding

To determine whether there was statistically significant relationships between mathematical processing skills, algorithmic problem-solving skills, and conceptual understanding, correlation coefficient (*r*) values of each question type were analyzed (Table 2). There were moderately positive and statistically significant relationships between students' mathematical processing skills and algorithmic problem-solving skills ($r = .32$, $r = .57$, $r = .58$, $p < .05$). Again, there were moderately successful ($r = .44$, $r = .57$, $p < .05$) and high ($r = .71$, $p < .05$) positive and significant relationships between students' algorithmic problem-solving skills and conceptual understanding. The relationship between mathematical processing skills and conceptual understanding was low level ($r = .13$, $p < .05$), positive and statistically significant for only Grade 9 students, and a moderately positive and statistically significant for other grades ($r = .39$, $r = .42$, $p < .05$). These relationships take the grade level into consideration. The correlation analyses between Q_m, Q_{cc}, and Q_{cu} obtained significant positive *r*-values between all three parameters, a pattern consistent across all grade levels. The strongest correlation was between Q_{cu} and Q_{cc} ($r = 0.70$) indicating a very strong association, followed by a more moderate relationship between Q_{m} and Q_{cc} ($r = 0.54$), and a much lower correlation between Q_{m} and Q_{cu} ($r = 0.36$).

Grade	Subject	Q_m	Q_{cc}	Q_{cu}
	Q_m	1.00		
9	Q_{cc}	0.32**	1.00	
	Q_{cu}	0.13	0.44**	1.00
	Q_m	1.00		
10	Q_{cc}	0.57**	1.00	
	Q_{cu}	0.39**	0.57**	1.00
	Q_m	1.00		
11	Q_{cc}	0.58**	1.00	
	Q_{cu}	0.42**	0.71**	1.00
	Q_m	1.00		
Total	Q_{cc}	0.54**	1.00	
	Q_{cu}	0.36**	0.70**	1.00

**Correlation is significant at the 0.01 confidence level (2-tailed)

Table 2: Correlation Matrix among Q_m, Q_{cc}, and Q_{cu}

Effects of Conceptual Understanding and Mathematical Processing Skills on Algorithmic Problem-Solving Skills

Determining the relationships between students' mathematical processing skills, algorithmic problem-solving skills, and conceptual understanding helped to interpret whether conceptual understanding and mathematical processing skills affect algorithmic problem-solving skills. In order to explain how far mathematical processing skills and conceptual understanding affect algorithmic problem solving skills, multiple linear regression analysis was performed (Table 3). We found a moderately positive and statistically significant relationship between mathematical processing skills and algorithmic problem-solving skills ($r = 0.54$) and a high-level positive and statistically significant relationship between algorithmic problem-solving skills and conceptual understanding ($r = .70$). However, when conceptual understanding points were controlled, there was a moderately positive relationship between mathematical processing skills and algorithmic problem-solving skills ($r = .43$); and when mathematical processing skills were controlled, there was a moderately positive relationship between conceptual understanding and algorithmic problem-solving skills ($r = .64$). In light of these results, there was a high-level positive and significant relationship between both mathematical processing skills and conceptual understanding and algorithmic problem-solving skills ($R = .76$, $R^2 = .58$, $p = .00$). Mathematical processing skill and conceptual understanding explained about 58% of the variance in algorithmic problem-solving skills. According to the results of t-test on the significance of regression coefficients, both conceptual understanding ($p = .00$) and mathematical processing skill ($p = .00$) had an effect on interpreting algorithmic problem-solving skills. However, according to the standardized regression coefficients (β), conceptual understanding had an effect on algorithmic problem-solving skills much more than mathematical processing skill. In conclusion, students' understanding of relevant subject and their mathematical processing skills affect algorithmic problem-solving skills.

Variables	*B*	*SE*	*β*	*T*	*P*	*Binary r*	*Partial r*
Constant	-0.84	0.23	-	-3.60	0.00	-	-
Mathematical processing skill	0.43	0.04	0.33	10.76	0.00	0.54	0.43
Conceptual understanding	0.67	0.03	0.58	19.12	0.00	0.70	0.64

Note. $R = .76$, $R^2 = .58$ $F(2.52) = 365.71$, $p = .00$.

Table 3: The Effect of Mathematical Processing Skills and Conceptual Understanding on Algorithmic Problem-Solving Skills

Qualitative Analysis of Students' Answers during Interviews

This study found that students' mathematical processing skills and conceptual perceptions have an effect on their algorithmic skills. Through the student interviews, it was established that students trying to do chemical calculations with only formulas are good at mathematical operations but bad at explaining the chemical calculations and at perceiving concepts. Following are some examples of students' answers to the interview questions (I = interviewer, S = student).

One interview question was: *If the density of 1.0L aqueous solution, prepared by using 6 moles of NaOH, is 1,2 g/mL, then what is the percentage of NaOH in this solution?*

I: The density of the solution is 1,2 g/mL. What does this mean?
S5: Sorry?
I: How has this density value been found? Or how much solvent and solute is there in a solution of this density?
S5: I see. Density is 12/10. So, there are 2 grams of solute in 10 mL of water.
I: Can you solve the 14th question about solutions aloud?
S5: Six moles salt in one L solution density is 1,2. 12/ 10x1 = 6x40. n= m/mA. I don't know. I can't do it.

Student 5 could do the mathematical operations for the question but could not solve the problem since he did not remember the formula and failed to comprehend the solution case at the submicroscopic level and what the terms referred to in the formulas. Because of the gaps in his conceptual knowledge, he had difficulty in solving problems or the problem was totally left unsolved. It was also seen that he held misconceptions about solution on a particular level.

I: Suppose you added some salt in a glass of water and observed the event with an imaginary microscope. Can you draw your observation?
[The student drew his observation.]
I: Can you tell me what is going on here? How does solution take place?
S5: The oxygen in water attracts the sodium, which has positive charge in salt. Therefore, the bond in NaCl weakens and separates.
I: Where do these (–) charge and (+) come from and become Na^+ *and* O^-*?*
S5: Since sodium is a metal, it gives electrons and gets (+) charge. The charge of hydrogen in water is (1+). Oxygen has – charge.

It was established that even though students wrote down the formulas correctly in algorithmic questions, they couldn't solve the problem. Even if they solved, they used incorrect concepts. For instance, students' inability to comprehend the solution process on a molecular level and to associate relations between concepts, such as density and concentration in solutions, can be the reason for their failure to solve problems.

I: What is the solution?
S4: Invisible dispersion of a substance in another substance.
I: How can you explain this dispersion thing you've mentioned?
S4: It enters the gaps in water, that is, air gaps. They scatter, enter these gaps in themselves. They scatter invisibly.
I: Well, salt, sugar enter gaps and dissolve but why doesn't oil?
S4: Can it be due to density?
I: How come?
S4: I don't know. Water stays at the bottom of oil. I've recently read something about the tensile force of water. It says tensile force is the reason how mosquitos float on water and not go down. Can this be the reason?
I: Can you solve the 14th question aloud?
S4: I cannot solve this question. I know all the formulas but still I can't.

It was established that the students' failure to comprehend the solubility concept on a molecular level depended on their inadequate knowledge on chemical bonds.

I: How does it separate into ions?
S8: It ionizes when we add salt into water and fill water voids.
I: How do you visualize space in water?
S8: You know, voids. It fills the space between water molecules.
I: Well, how about the solution of sugar?
S8: Sugar doesn't ionize. A bond forms between sugar and water.
I: Just like the bond between oxygen and carbon?
S8: No. Not through electrons. An attraction takes place in between.
I: How does this attraction happen?
S8: I don't know.
I: Why can't oil dissolve in water?
S8: The density of oil is small. The reason must be that water is heavier.

When the student's solution of algebraic questions is analysed, it is clear that his inadequacy in conceptual understanding reflects the way he solves the problem:

I: What does a solution of 20 % by mass mean?
S8: 20 g of salt in 100 g of water has been dissolved.
I: Can you solve the 14th question about solutions?
S8: dsu = 1 NaOH, 0,2 has changed it. What can I do? If 0,2= m/, m=0,2 I don't know.

Furthermore, it was found during the interviews that students with solid conceptual knowledge are better at chemical calculations. Students 2 and 7 solved this question easily by noticing the g/mL unit and transforming 1 L into 1000 mL, which is an indicator that they have structured density concept more meaningfully with units rather than using a memorized density formula. Mathematical processing skills helped the students solve the problem in two operations.

I: Can you solve the 14th question in the test aloud?
S2: Okay. 6 moles salt is 240 g. If 240+water /1000 = 1,2; water is 960 g. If there is 240 g salt in 1200 g, there is 20 g in 100 g.
S7: Okay. If 1L 1000mL. 1,2.1000 = 1200 = 240 + m, m = 960. Mass of water is 960 g. Total solution is 960 + 240 = 1200g.
If there is 240 g salt in 1200 g., how much % is there? Zeros are cancelled. 240 divided by 12 is 20.

Student 7 modelled the solution correctly, which may mean that it had a positive effect on the solution of the chemistry problem.

I: How does salt dissolve? What makes it dissolve?
S7: It can be water, water separates the bonds.
I: Well, why is it that no solution takes place in oil?
S7: The difference of size or the shapes may affect.
I: What kind of effect?
S7: I don't know but since oil is a bigger, water can't break the molecule into pieces but salt is small, or more water separates salt into ions.

Morever, the adequate knowledge of Student 7 on concepts such as stoichiometry, particulate nature of matter, mole, and his problem-solving skills helped him solve the second algorithmic problem step by step in a short time.

I: *Look at Question 2 (Question 2: Solid carbon (C) reacts with oxygen gas (O_2) to form carbon dioxide (CO_2). 2,4 grams of solid carbon reacts with oxygen gas of 2,24 L volume at Standard temperature and pressure in a closed container. Given this, which of the statements below is false? (C = 12,0g/mole O = 16,0g/mole))*

S7: *2,4 grams of carbon and 2,24 L of oxygen react in order to form water. 2,4 grams of carbon 2,4/12 = 0,2 mole. Mole of oxygen. 2,24/ 22,4 = 0,1 mole. 0,1 mole of 0,2 mole carbon reacts. 0,1 mole remains. 0,1 mole carbon dioxide forms.*

I: *Okay. After the reaction has finished, there is 0,1 mole carbon dioxide, 0,1 mole carbon in the container. I want to get one kind of particle in the container, what can I do?*

S7: *............excess 0,1 mole carbon remained. I can add oxygen that reacts with it.*

I: *How much? Can you mention quantity by volume, mass, and molecule number?*

S7: *I need 0,1 mole as mass. I can also add gas by 2,24 L. Molecular mass is 32 grams. I need to add 0,1 mole. I can add 3,2 grams.*

I: *How many oxygen molecules do you have to add?*

S7: *If there are $6{,}02.10^{23}$ molecules in one mole, there are $10^{-1}.6{,}02.10^{23}=6{,}02.10^{22}$ in 0,1 mole.*

Students answered both the algorithmic questions about gases in the interview using formulas correctly, and they answered conceptual questions using the ideal gas law in a correct way. Student 10's results on the MPC Test were high.

I: *There was some water vapor in the container. Can you draw that?*

S10:

I: *Suppose we took some of the water vapor out of the container. Can you show the change in the container by drawing?*

S10:

I: *We have an empty bottle with an open lid and we pour water in it with the help of a funnel. At first, pouring is easy but as time passes, it gets harder. What is the reason?*

S10: *There is air in the bottle. As water fills in, the gas in the bottle tightens. Pressure rises. When we uplift the funnel a bit, it gets easier to pour water in. Since air molecules become less, pressure becomes less, too.*

I: *Ok, I'll ask you a problem now and I want you to solve it aloud. One mole of H_2 gas covering 600mL volume at 25^oC has 4.08 atmospheric pressure. To how many mL should its volume be changed if we want the pressure of this gas to be 16.32 atm at the same temperature?*

S10: *We will use PV= nRT*

$P_1V_1 = n_1RT_1$

$P_2V_2 = n_2RT_2$ $\quad P_1V_1 = P_2V_2 \quad 4.08x600 = 16.32xV_2 \; V_2 = 600/4 = 150L.$

The student noticed the ratio between 16.32 and 4.08 and solved the problem easily, which showed his high mathematical skills. As the interview went on, it was clearly understood that comprehension at the molecular level made it easier for him to solve the chemistry question about gases in a short time as well.

Student 6 not only used formulas and rules while answering the algorithmic questions but also explained conceptual-content questions exactly and correctly thinking on a molecular level during the interview. His achievement on the MPC Test was high.

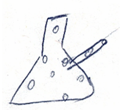
I: *Suppose you have taken one molecule from ice, one from water, and one from water steam. What will you say about their temperature?*

S6: *The temperatures will be different, because temperature increases the kinetic energy of molecules. Molecules will speed up.*

I: *What about the mass of these three?*

S6: *Their masses will be the same: $18/N_A$ g.*

I: *There is some water steam in the container. Can you draw it?*
S6:

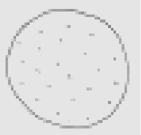
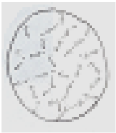
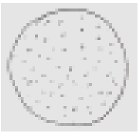
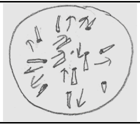
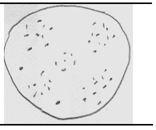


I: *Suppose we have taken away some of the water steam. Can you draw what change will occur?*
S6:

I: *We have an empty bottle with an open lid, and we pour water in it with the help of a funnel. At first, pouring is easy but as time passes, it gets harder. What is the reason?*
S6: *As water fills in, the gas in the bottle tightens. Pressure rises.*
I: *When we uplift the funnel a bit, it gets easier to pour water in. What is the reason for this?*
S6: *...when we uplift the funnel, some of the air goes out. Since air molecules become less, pressure becomes less, too.*
I: *One mole of H_2 gas covering 600mL volume at $25^{o}C$ has 4.08 atmospheric pressure. To how many mL should its volume be changed if we want the pressure of this gas be 16.32 atm at the same temperature?*
S6: *We will use PV= nRT.*
$P_1V_1= P_2V_2$
$4.08x600= 16.32xV_2$
$V_2=600/4 =150$

The results of the MPC Test have shown that students should have adequate conceptual understanding about that specific subject and mathematical processing skills in order to be able to solve algorithmic questions about chemistry. During the interviews, it was established that students with conceptual understanding appropriate for scientific view could solve algorithmic questions while students without appropriate (adequate) conceptual understanding and weak mathematical processing skills could not solve algorithmic questions.

However, when students' answers were taken into consideration during interviews, it was seen that they had conceptual misunderstanding and a lack of knowledge in chemistry subjects. For instance, different students' answers including misconceptions and incorrect drawings about a question are below. The question was, *when the temperature of the gas is decreased to -5 ℃ in a constant-volumed steel tank filled with H_2 gas in 20 ℃ temperature and 3 atm pressure, what becomes of the H_2 molecules distribution in the tank?* (Niaz & Robinson, 1992). Students' prevailing conceptions were: *when temperature rises, gas particles want to come out … accumulates at sides … when it gets colder, activity decreases and they accumulate in the middle*. Some students explained the conception that *as temperature rises, activity of the particles increase* by drawing much more particles. Some sample drawings are given below (Figure 2).

Student	20°C	100°C	-50°C
A			
B	No drawing		

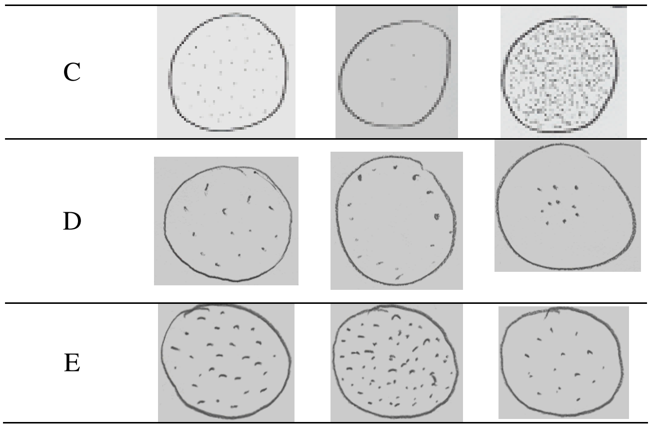


Figure 2: Students' Drawings of Distribution of Gases at Different Temperatures

Discussion

Although many learning strategies have been developed in science education, students still do not show the expected achievement about understanding basic concepts and solving questions. This research, in which students' conceptual understanding, mathematical processing skills, and problem-solving skills about chemistry subjects were compared, has made it clear that conceptual understanding and mathematical processing skills (a) affect algorithmic problem-solving skills and (b) can be used for predicting algorithmic problem-solving skills.

In the literature, it is mentioned that conceptual knowledge of students is effective in chemical calculations and solving stoichiometric problems (Niaz ;1995a). Also, this result is consistent with Chiu's (2001) results about algorithmic problem solving and conceptual understanding of high school students in Taiwan; she defined students as high problem solvers and high conceptual thinkers.

As stated in the literature, interviews have shown that students' solving of algorithmic questions correctly is not an indicator of their understanding of concepts, such as chemical and physical changes in problems on macroscopic, molecular, and symbolic levels (Nakhleh, 1993; Nakhleh & Mitchell, 1993; Niaz, 1995a, 1995b; Niaz & Robinson, 1992; Pickering, 1990; Stamovlasis et al., 2005). For instance, some of the aforementioned students in Figure 2 who had some misconceptions about gases solved algorithmic problems about this subject correctly. In addition, we found that students who use mathematical processing skills well and consider concepts in respect to mathematical relations are better at solving algorithmic problems. To illustrate, many students answered Question 11 in the test as:

$$y\,S + x\,Fe \rightarrow Fe_xS_y$$

$$1/6 \text{ mol } 1/3 \text{ mol}$$

and found FeS_3 according to ratio of mol relations. Those who found mathematical operations difficult, such as in mole concept and gases questions, did not complete the solution of the problem.

According to the findings of the MPC Test, there is a significantly positive relationship between algorithmic problem-solving skills and conceptual understanding and also mathematical processing skills for all grade levels. In light of the students' answers throughout the interviews, it has been concluded that conceptual understanding along with mathematical processing skills contribute to the solution of chemical problems. The MPC Test has showed that Grade 11 students are more successful at mathematical, algorithmic, and conceptual chemistry questions than others; they are better at mathematics questions because they practice mathematical skills while studying for the university entrance examination; and they are successful at chemistry problems because they have comprehended chemistry concepts on a molecular level and have good algorithmic problem-solving skills. Very likely, they developed the necessary strategies in different types of problems, which may explain their high results in this study. In addition, most of the chemistry questions in such examinations are related to mole, stochiometry, gas, and solution; therefore, when preparing for the examinations, students especially concentrate on these concepts.

When the interviews are considered, it was viewed that some students did not try hard enough to understand chemistry concepts. They acted unwillingly, they did not make an effort to learn the concepts and apply them to their questions, and they thought these were not necessary for the examinations taken at schools. Students' achieving high marks on the examinations prepared in a traditional style that made them feel they truly had learned chemistry so they did not try hard enough and spend time to learn concepts on a molecular level.

Suggestions and Implications

The results from this study indicate that conceptual understanding and mathematical skills have an effective role on students' solving chemistry problems correctly. If an important goal of chemistry education is to help students develop their understanding of concepts and acquire skills in problem solving, we must endow them more than just algorithmic capabilities, such as higher oriented curricula, teaching materials, teaching strategies to be developed and implemented (Zoller, 2002).

Many chemistry concepts are abstract so care must be taken that they are introduced concretely (Heyworth, 1998). One factor affecting the learning of abstract concepts is students' ability to visualize the particular structure of matter at the microscopic level. Because most chemistry concepts are represented symbolically, the connection between symbolic representation, macroscopic concept, and submicroscopic concept must eventually be made. According to Hill and Petrucci (1996), drawings, computer diagrams, and photographs will help students visualize chemical reactions at macroscopic and microscopic levels. "Taking into account that lack of understanding makes conceptual questions difficult for most students, teachers and schoolbook authors should place emphasis on providing students with an understanding of chemistry" (Gillespie, 1997, as cited in Stamovlasis et al., 2005, p.113*).* In addition, all students, but especially those experiencing difficulty with conceptual questions, must continually be given practice, encouragement, and support for dealing with such questions, with the aims both to improve their capabilities and develop their confidence (Stamovlasis et al., 2004).

According to Heyworth (1998), even with the best instruction, students have some misconceptions and teachers should continually monitor students' understanding and correct any misconceptions that are confirmed. Dahsah and Coll (2007) found that "the literature for constructivist-based teaching suggests that an understanding of students' prior conceptions provides a useful insight into their thinking, and may allow teachers to devise pedagogies appropriate for their students" (p. 240). Conceptual-change pedagogy, which employs constructivist/active and cooperative modes of teaching and learning, is promising for overcoming some of the misconceptions (Tsaparlis & Papaphotis, 2009). Both approaches—including constructivist ones suggested by educators (Bodner, 1986) and science history and nature of science in education (Niaz, 1995b, 1998)—will help students develop their conceptual framing. "This understanding allows for good problem recognition and setting up of a qualitative representation of the solution procedure with strategies that make efficient use of cognitive processing capacity." (Heyworth, 1998, p. 24).

To improve problem-solving skills, problem-solving strategies should be given emphasis. When teaching students how to solve numerical problems, teachers should ask students to think rather than to simply memorize and use algorithms without understanding (Boujaoude & Barakat, 2000). We should allow students the opportunity to think aloud while solving a problem and to derive qualitative, non-mathematical procedures for problems; this could facilitate qualitative understanding and help teachers and students to identify misconceptions (Heyworth, 1998). In brief, students' background knowledge about conceptions should be measured before giving them basic concepts; subjects should only be introduced after detecting and removing their misconceptions. Algorithms should be used in algebraic questions, and students should be encouraged to use them *but* they should be developed and used in parallel with conceptual knowledge. Therefore, teachers should be concerned whether students are successful in this subject—that they learn chemistry and like chemistry. They should also mind whether students use conceptions in problem solving, connect with real life, and think critically.

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