Conceptual learning versus problem solving: there is a difference. J Chem Educ

ARTICLE *in* JOURNAL OF CHEMICAL EDUCATION · FEBRUARY 1993

Impact Factor: 1.11 · DOI: 10.1021/ed070p190

Mary Nakhleh
Purdue University

Concept Learning versus Problem Solving

There Is a Difference

Mary B. Nakhleh and Richard C. Mitchell
Purdue University, West Lafayette, IN 47906

Chemical educators have often assumed that success in solving mathematical problems should indicate mastery of a chemical concept. To this end, we have developed algorithms. However, Nurrenbern and Pickering (*1*) and Pickering (*2*) found little connection between solving an algorithmically-based problem and understanding the chemical concept behind that problem. Sawrey (*3*) further supported Nurrenbern and Pickering's findings.

These studies quantitatively evaluated success in solving a conceptual problem versus a similar algorithmic problem. These studies found that many students could not use chemical concepts to solve conceptual problems. These findings were further supported by Nakhleh (*4*).

Nakhleh found that across all levels of first-year chemistry students (from remedial to honors) conceptual problem-solving ability lagged far behind algorithmic problem-solving ability. She determined through the use of paired exam questions, that a sizable percentage (31% in that sample) of our first-year students are low conceptual/high algorithmic students; students adept at solving problems with algebraic equations, but having only limited understanding of the chemistry behind their algorithmic manipulations.

In the present study our objective was to ascertain what students do think about when they solve conceptual and algorithmic problems and to determine further if there are differences and/or preferences in their approach to each.

We, therefore, used paired exam questions on gas laws to select students for interviews. In the interview we probed their conceptual understanding and their problem solving in detail. We tried to determine how the students went about solving a conceptual problem versus an algorithmic problem. We also endeavored to probe their preferences for solving either type of problem.

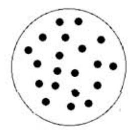
Method

Our sample consisted of 60 freshmen chemistry students who were all enrolled in the same introductory course for declared chemistry majors. No other majors were represented in this sample. The professor for the course used a traditional problem-oriented lecture approach.

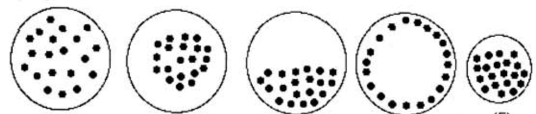
This study was completed in two parts. The first part of the study used the paired questions technique to identify students as being either conceptual or algorithmic problem solvers. Two problems—one conceptual gas law problem and one algorithmic gas law problem—were placed on the third exam in the course where gas laws were being examined. Success or failure on these problems were recorded and students were grouped in one of four categories: High Algorithmic/High Conceptual (answering both problems correctly); High Algorithmic/Low Conceptual (answering the conceptual problem incorrectly); Low Algorithmic/High Conceptual (answering the algorithmic problem incorrectly); Low Algorithmic/Low Conceptual (answering neither problem correctly).

Problem I.

The following diagram represents a cross-sectional area of a rigid sealed steel tank filled with hydrogen gas at 20 °C and 3 atm pressure. The dots represent the distribution of all the hydrogen molecules in the tank.



Which of the following diagrams illustrate the most probable distribution of molecules of hydrogen gas in the sealed steel tank if the temperature is lowered to –5 °C? The boiling point of hydrogen is –252.8 °C.



(A)* (B) (C) (D) (E)

Correct answer: (A)

Problem II.

Calculate the maximum weight of SO_3 that could be produced from 1.9 moles of oxygen and excess sulfur.

$2S + 3O_2 \rightarrow 2SO_3$

Problem III.

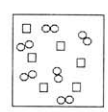
0.100 mole of hydrogen gas occupies 600 mL at 25 °C and 4.08 atm. If the volume is held constant, what will be the pressure of the sample of gas at –5 °C?

(a) 4.54 atm (b) 3.67 atm (c) 6.00 atm (d) 2.98 atm
(e) 4.08 atm

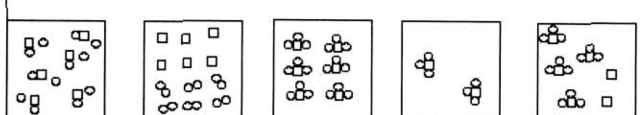
Correct answer: (b)

Problem IV.

The equation for a reaction is $2S + 3O_2 \rightarrow 2\ SO_3$. Consider the mixture of S (□) and O_2 (oo) in a closed container as illustrated below:



Which of the following represents the product mixture?



(A) (B) (C) (D) (E)

Correct answer: (E)

Problems used for student interviews.

In the second part of this study, one of us (Mitchell) interviewed six students, two from three of the four categories. No students were available from the Low Algorithmic/High Conceptual category, because of the low number of students in this category. Students were individually interviewed for approximately 50 min. In the interview, each student worked through the same two problems from the exam and an additional pair of stoichiometry problems while verbalizing their thoughts. The figure displays the interview problems.

The interview was conducted using techniques similar to the interview-about-instances technique of Osborne and Freyberg (*5*) and the think-aloud protocols of Larkin and Rainard (*6*). The interviewer was trained by the first author. The interviewer briefed all subjects on the nature of the interview and worked a practice problem, demonstrating what was meant by thinking aloud. The subject was then asked to complete a practice problem as well as practice thinking aloud. This was followed by asking the subject to solve aloud the four problems as described earlier. Finally, the subjects were asked to compare the conceptual problem to the corresponding algorithmic problem to determine their perception of difficulty, as well as their preference for solving either type of problem.

All students were interviewed within a period of four days, immediately following their final exam in the course. The interviews were transcribed and analyzed. Final course grades also were recorded for each student.

Results

Part One of our study sought to identify conceptual/algorithmic problem solvers based on their responses to the

Table 1. Comparison of Chemistry Majors' Algorithmic vs.Conceptual Problem Solving Abilities

	High Algorithmic Ability	Low Algorithmic Ability	Totals
High Conceptual Ability	43.3%	5%	48.3%
Low Conceptual Ability	41.7%	10%	51.7%
Totals	85.0%	15%	

pair of problems on the exam. The results tabulated in Table 1 represent the percentage of chemistry majors in each of the four categories.

Part Two of this study analyzed the transcribed interviews, parts of which will be included later in this paper. Table 2 records the success (S) or failure (F) on each of the four problems used in the interview, the subject's preference for solving the algorithmic or conceptual problem of the pair, and their final course grade.

The "preference" data may be misleading, as the students frequently put important stipulations on their preferences. These stipulations will be a later focus in this paper.

The subject code (e.g., LA.LC.01) indicates the student's algorithmic or conceptual scoring as well as his/her place in the interview schedule. For instance LA.LC.01 indicates that this subject was identified as low algorithmic ability, low conceptual ability (as determined by Part One of this study) and was the first person to be interviewed. Table 2 indicates use of an algorithm (Yes) or no use of an algorithm (No) in attempting to work the conceptually-based problems.

Table 2. Final Course Grades, Success on Interview Problems and Preference Comparisons for Students

Subject Code	Final Grade	Conceptual	Algorithmic	Preference
		Gas Problems		
LA.LC.01	A	S[a]	S	algorithmic
HA.LC.02	A	S	S	conceptual
HA.HC.03	A	S	S	conceptual
HA.HC.04	B	S	S	conceptual
HA.LC.05	A	S	S	algorithmic
LA.LC.06	C	S	S	algorithmic
		Stoichiometry Problems		
LA.LC.01		F	S	algorithmic
HA.LC.02		S	S	conceptual
HA.HC.03		S	S	algorithmic
HA.HC.04		S	S	conceptual
HA.LC.05		S	S	algorithmic
LA.LC.06		S	S	conceptual

[a]S indicates success in working the problem. F indicates failure.

Analysis of Data

Performance in the conceptual/algorithmic exam questions indicates that more than **50%** (51.7) of our students fall in the low conceptual category. That is, they do not demonstrate understanding of the chemistry concepts, or, cannot apply those concepts.

One should keep in mind that this sample represents declared chemistry majors, the students most likely to desire to understand these concepts. Further, these are good students. In fact, four of the six students interviewed have an "A" average final grade.

The interviews also produced interesting results. All six subjects answered both gas law problems correctly. This was not surprising as they had seen those exact problems on a previous exam. However, we were basically interested in how these students solved those problems, particularly the conceptual gas law problem.

Half of the students used an algorithm (an actual gas law) to solve this problem. Two additional students used an elimination approach, eliminating the obviously wrong answers and then deciding between the remaining choices. We suggest that this "test taking strategy" also may be considered an algorithmic approach, for it was clear that the students did not truly understand the kinetic-molecular theory concept behind this problem. Only one of the students clearly demonstrated conceptual understanding of this item. This student had been identified as a high algorithmic/high conceptual problem solver.

Problem IV is a conceptual stoichiometry problem that none of the students had ever seen before. The students that missed this problem were also classified as low conceptual problem solvers. Two of the four subjects that correctly solved the problem were identified as high conceptual problem solvers and high algorithmic problem solvers. It is not surprising that they solved this problem.

The most absorbing case is the second student who was identified as a high algorithmic and low conceptual problem solver. This student appently fell back on his algorithmic skills to complete this problem. This seems to be typical of a high algorithmic problem solver. In three of the six cases, Problem IV was solved using an algorithm that is clearly unnecessary in solving this problem.

By "algorithm" here, we mean that the subjects drew the Lewis structure of SO_3. They started by counting the total number of valence electrons and pairing them to the central sulfur atom. They frequently drew or indicated the possible resonance structures. They were elated that they could do this. These observations indicate the overriding importance of finding a formula or an algorithm.

In this problem, it is only important to see that there are three oxygen atoms around each sulfur atom or, specifically, three circles around one square. However, the subject would typically complete the Lewis structure, then construct the circle/square model from that structure and **then** realize it was unnecessary to use the Lewis structure to get the model. If the concept of molecular formula and the ideas behind the subscripts in that formula were truly meaningful to the student, the search for a Lewis structure should not have occurred.

The interviews suggest that subjects who are identified as high algorithmic problem solvers use algorithms to solve conceptually based problems regardless of their conceptual problem-solving ability. While understandable that an algorithm would be used to solve an algorithmic problem, the data in Table 3 show that in all cases, a high algorithmic subject used an algorithm to solve one or both of the conceptual problems as well. It may be that our students, having done hundreds of problems requiring calculations, do not trust their conceptual understanding of the chemistry involved.

We also sought to elicit students' preferences for solving algorithmic or conceptual problems. Table 2 demonstrates quite a split between preferences. The data is additionally complicated by the stipulations that the subjects placed on their preferences. A majority of the subjects said that they prefer the conceptual problems (Problems I and IV) in terms of generally working problems, such as for homework assignments. They would not, however, like to be graded on such problems on exams. Because their frame of reference is a one-hour exam with many algorithmic problems on it, it is understandable that they would not want a similar size exam of conceptually based problems requiring more thought. Typically subjects were more confident of their algorithmic answers, yet seemed more gratified when solving the corresponding conceptual problem, as this transcription from subject HA.LC.02 relates:

I: . . .in terms of sitting down and working a problem, not on a test, which one would you prefer to try and. . .

S: Well, I kind of like Item One also because its' it's unique; it's something different. I mean cause this stuff I've been doing, you know, for the last couple of years, you know,just problems. This is different, you know. It's not something I'd want to be graded on, I mean it's kind of fun to do though and just think about. Cause, you know, Item IV of all of them, you know, it was the most fun because I really had to think about it; i was unique. I had never seen anything like that before."

Table 3. Use of an Algorithm To Solve a Conceptually Based Problem Not Requiring Algorithmic Solution

Subject Code	Gas Problem (Problem I)	Stoichiometry Problem (Problem IV)
LA.LC.01	No	No
HA.LC.02	Yes	Yes
HA.HC.03	No	Yes
HA.HC.04	Yes	Yes
HA.LC.05	Yes	No
LA.LC.06	No	No

Summary

While 85% of our students are good algorithmic problem solvers, able to manipulate equations and able to achieve good grades in the course, do these algorithmic calisthenics really serve any purpose? It does not seem that presenting an algorithm and demonstrating the myriad of problems that can be solved using that algorithm facilitate understanding of the underlying concept. Our teaching, therefore, must take on a much more concept-based framework.

The work in the area (*1–4*) suggests strongly that our current methods of teaching chemistry are, perhaps, not teaching chemistry, but teaching how to get answers to selected algorithmic problems. This study supports efforts being made to involve conceptual-teaching pedagogies into our classrooms. We have identified a reliance of our students on algorithms to solve problems, even problems specifically intended for conceptual solution. We have reaffirmed the notion that current algorithm-based teaching does not necessarily lead to conceptual learning. We look forward to further studies that may support our findings.

Literature Cited

1. Nurrenbern, S.; Pickering, M. *J. Chem. Educ.* **1987**, *64*, 508.
2. Pickering, M. *J. Chem. Educ.* **1990**, *67*, 254–255.
3. Sawrey, B.*J. Chem. Educ.* **1990**, *67*, 253–254.
4. Nakhleh, M. *J. Chem. Educ.* In press.
5. Osborne, R.; Freyberg, P. *Learning in Science*. Heinemann: Auckland, New Zealand, **1985**.
6. Larkin, J.; Rainard, B. *J. Res. Sci.Teach.* **1984**, *21*, 2 49.