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Solving Numerical Problems in Chemistry and Physics: Ideas for High School Teachers

Abstract

This paper presents literature-based ideas for teaching numerical problem solving in high school science, specifically in Chemistry and Physics. Factors contributing towards success in problem solving are discussed. The importance of prior subject-matter knowledge, and a single strategy applicable to different types of problems are emphasised. Selected examples of problems with solution strategies from high school Chemistry and Physics are outlined. Implications for problem solving in science teacher preparation are explained. Recommendations for science teachers to utilise in their teaching are provided.

What is Problem Solving?

Problem solving involves a series of cognitive actions with a goal originating from instructions in a problem to the desired solution or answer (Chi, Glazer, and Rees, 1982). Newell and Simon (1972) define problem solving as determining a solution pathway through a problem space from the initial state of the problem to a desired answer. The initial problem state consists of information in the problem plus knowledge about the problem. The problem space consists of the initial problem state, solution path and goal state. Strategies and processes employed in the problem space are critical to success in problem solving; they considerably differ between successful and unsuccessful problem solvers (National Academy of Sciences, 2000; Newell and Simon, 1972; Chi et al., 1982). Subject matter content knowledge base of successful problem solvers is strong and deep compared to unsuccessful problem solvers. Successful problem solvers can easily and flexibly access needed information and knowledge for solving a problem compared to unsuccessful problem solvers. Successful problem solvers can qualitatively visualise the problem space before proceeding with solving the problem whereas unsuccessful problem solvers are quick to take refuge under formulae.

One key factor essential to understanding the difference between success and failure in problem solving was discussed by Whitehead (1929) in "The Aims of Education and Other Essays" when dealing with passive learning and inert knowledge. Inert knowledge may be defined as what is recalled under explicit cues, but not applied spontaneously in solving problems. Passive learning leads to inert knowledge and meaningful learning to active knowledge. So in problem solving situations the capability of the problem solver to recognise the problem situation, bring to remembrance all the background knowledge and information needed to work forward in solving the problem depends on whether the related background knowledge and information is active or inert (Kumar, 2010). Therefore, the quality of the teaching strategies used by teachers impacts how students learn, and solve problems. In this context, it should be made clear that teaching students to memorise information, formulae and problem solving strategies by rote learning is excluded from discussion and discouraged by the authors.

Science teacher training programmes should develop successful problem solving skillset in their candidates. According to Ekici (2013) about 28% of pre-service teachers in science have no ideas about how to improve problem solving skills among students while a majority of them believed it could be improved by helping students with improving their problem solving process. Student's ability to perceive the nature of the problem task and awareness of solution strategies are key to their success in problem solving (Dostal, 2015). The ability of the students to clearly understand the question, to perceive the problem, and to recall similar conceptual information related to problem situations affect success in problem solving (Tambychik and Meerah, 2010).

In dealing with Chemistry problem-solving Heyworth (1998) recommended improving student conceptual understanding of the topic before expecting them to solve problems.According to Phonapichat and Sujiva (2014) unsuccessful problem solvers were unable to figure out what is expected because they disliked reading long problems, were quick to guess and not think about the problems, were unable to comprehend long problems, and lacked an understanding of the information and knowledge needed to solve problems. How to help students become successful problem solvers is a challenge facing teachers at all levels and in all subject areas. The following discussion will highlight successful problem solving strategies in science with selected examples of Chemistry and Physics problems at the high school level. The examples are selected to represent a medium level of difficulty and the strategies easily transferable to a wide range of topics.

Example of Chemistry Problem Solving

The problem chosen for Chemistry involves the calculation of molarity of a solution.

The problem - A solution contains 20 grams of Sodium Nitrate ($NaNO_3$) in 500 mL of water. Calculate the molarity of the solution. Given atomic mass of Na = 23; N = 14; O = 16.

The ability to recognise the problem statement –what factors are present in the problem statement and the goal – state what is to be accomplished is necessary to develop solution strategy in the problem space that will lead to success in solving the problem. An understanding of the Periodic Table of elements, atomic mass, molecular formula units and unit conversion, solutions, solutes, solvents and basic mathematics are necessary to successfully solve a molarity problem in Chemistry. Also, reading comprehension at the elementary grade level is essential besides the ability to visualise the strategies and processes involved in the problem space.

Step 1. Calculate the Molar mass of sodium nitrate ($NaNO_3$).

$$23\text{ g} + 14\text{ g} + 16(3)\text{ g} = 85\text{ g } NaNO_3$$

Step 2. Calculate the number of moles by dividing the mass of sodium nitrate by molar mass.

20 g $NaNO_3$/ 85 g $NaNO_3$ = 0.235 moles of $NaNO_3$

Step 3. Convert the units for the amount of solvent from millilitres (mL) to litres (L).

Amount of Solvent (Water) = 500 mL = 0.5 L

Step 4. Calculate the Molarity by dividing the number of moles of sodium nitrate by the volume of solvent.

Molarity of the $NaNO_3$ Solution = 0.235 moles of $NaNO_3$ / 0.5 L of Water = 0.47 M

This protocol concurs with the protocol reported by Heyworth (1989) in solving a similar molarity problem by successful problem solvers using paper and pen method. A secondary analysis of the solution profiles from the Kumar and Helgeson (1996) study of 60 high school Chemistry students solving a Chemistry molarity problem using a computer platform ("Hyper Chemistry") in Apple Powerbook and NEC PenPoint computers showed the above solution protocol in the solution paths of successful problem solvers.

Examples of Physics Problem Solving

In order to become a better Physics problem-solver the following things need to be in place.

(1) The student must know and understand the principles of Physics and,

(2) The student must have a strategy that is applicable to different situations in Physics.

The strategy is not just memorising and plugging-into formulas, as unsuccessful problem solvers do. Instead, qualitatively thinking and visualising the problem situation, and developing a mental map of a solution strategy for proceeding are recommended as the best approach. With practice, a strategy with generalisable patterns may develop over time. (Zemelman, Daniels, and Hyde, 2012)

The results of a study by Reddy and Panacharoensawad (2017) indicated that poor mathematical skills and lack of understanding the problem are also major obstacles in the domain of problem solving in Physics.

As with so many other learning activities, it may be useful to develop an algorithm, which breaks a problem solving strategy into a series of steps. According to Persin (2000) this strategy has five major steps:

Step 1. Read the problem carefully and write down what was given as a list of labelled quantities.

Step 2. Determine what you have to find and label it with a variable as well. Make sure you are able to visualise the steps toward the solution in qualitative terms.

Step 3. Look over your list of equations and determine which one will solve the problem.

Step 4. Solve the equation for the unknown.

Step 5. Substitute-in the values of the given information and calculate the solution.

At this stage of our discussion, there are physics terms and/or concepts that a student needs to understand. These concepts need to be learned as they are taught, to keep from falling behind.

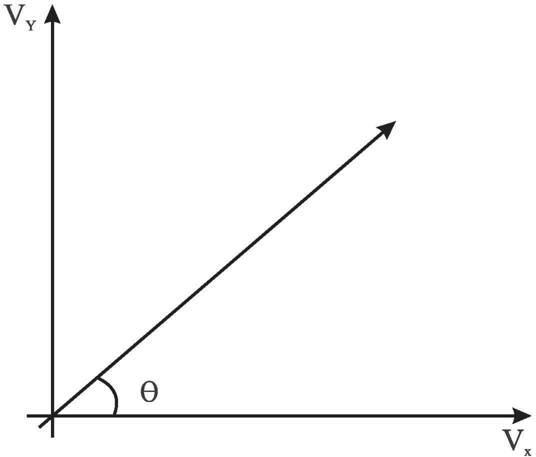
One part of learning how to solve a problem is to know what approach to use. The student will need to recall the concepts and principles that are useful in solving the problem. For example, just to name a few from Serway and Faughn (2006):

- If linear motion is involved, use the kinematics definitions of velocity and acceleration, along with the equations of motion.
- For vector problems, use SOHCAHTOA to find the x and y components of the given vector. If components are given, use the Pythagorean theorem for the resultant.
- If forces are involved and objects interact due to these forces, use Newton's Laws of Motion, particularly the 2nd Law, F = ma.
- The concept of forces that act over a time interval and cause objects to change their velocities suggests using Conservation of Momentum.
- Frequently in situations involving thermal physics or electromagnetism, the principle of Conservation of Energy is useful.

Now let's take a detailed look at how to use the steps while solving some problems.

Example 1: A cannonball is projected from the surface of the Earth with an initial velocity of 85.0 m/s at an angle of 35.0° with the horizontal. How fast is it moving in the x-direction, and how fast in the y-direction, respectively?

a. 69.6 m/s and 48.8 m/s
b. 48.8 m/s and 69.6 m/s
c. 69.6 m/s and 42.3 m/s



Visualising the Problem

Solution: Using the properties of vectors.

Given: Initial velocity, v = 85.0 m/s

Angle of projection, θ = 35.0°

Find: Velocity in the x-direction, v_x = ______

Velocity in the y-direction, v_y = ______

$v_x = v \cdot \cos(\theta) = 85 \cdot \cos(35) = 69.6$ m/s

$v_y = v \cdot \sin(\theta) = 85 \cdot \sin(35) = 48.8$ m/s

Answer is choice a. 69.6 m/s and 48.8 m/s

Example 2: An automobile moving along a straight track changes its velocity from 40.0 m/s to 80.0 m/s in a distance of 2.0×10^2 m. What is the acceleration of the vehicle during this time?

a. 8.0 m/s^2
b. 9.6 m/s^2
c. 12 m/s^2
d. 6.9 m/s^2
e. 0.20 m/s^2

Solution: From Galileo's study of motion, 4 equations:

Given: Initial velocity, u = 40.0 m/s

1. $\Delta s = v_{avg} \cdot \Delta t$, with $\Delta s = s - s_0$, $v_{avg} = (u + v)/2$

   Final velocity, v = 80.0 m/s

2. $v = u + a \cdot \Delta t$

   Displacement, $\Delta s = 2.0 \times 10^2$ m

3. $v^2 = u^2 + 2a \cdot (\Delta s)$

   Find: Acceleration, a = _______

4. $s - s_0 = u \cdot t + \frac{1}{2} a \cdot (\Delta t)^2$

Based on the given information, equations 1, 2, and 4 can be eliminated from the solution since we were not given the change in time, Δt. Therefore, we should use equation 3, $v^2 = u^2 + 2a \cdot (\Delta s)$ and solve for the unknown, acceleration, a.

Solving for acceleration, we get,

Substituting the given, we get,

Therefore, our answer is choice c, which is 12 m/s^2

Example 3:A 10.0 kg mass is dropped from a height of 15.0 m. Neglecting air friction, and using 9.81 m/s^2, find its velocity when it strikes the ground?

a. 18.0 m/s
b. 17.2 m/s
c. 12.7 m/s
d. 16.9 m/s
e. 20.2 m/s

Solution: (using Conservation of Energy):

$K_i + U_i = K_f + U_f$ with $K = \frac{1}{2} m \cdot v^2$ and $U = mgh$

or

$\frac{1}{2} m \cdot v_i^2 + mgh_i = \frac{1}{2} m \cdot v_f^2 + mgh_f$ and g = 9.81 m/s^2

Given: Initial kinetic energy, $K_i = 0$

Since the mass was dropped, and $v_i = 0$

Mass, m = 10.0 kg

Initial height, $h_i = 15.0$ m

Final potential energy, $U_f = 0$ since the mass strikes the ground

Find: Velocity when striking the ground, v_f = ______

Therefore, $0 + mgh_i = \frac{1}{2} m \cdot v_f^2 + 0$. Solving for v_f and noticing that the mass, m, cancels

We get, $v_f = 17.2$ m/s , choice b

Discussion and Implications

Students may use different tools or tactics with differing areas of Chemistry and Physics, but the overall strategies remain the same. Sometimes, students may have already acquired some problem-solving skills and habits from previous courses in Biology, Mathematics, or Computer programming. Like other areas of learning and life, some of these habits may be beneficial and some may actually hinder your progress in learning how to solve Chemistry and Physics problems. So, in learning this approach, a student must be willing to try new ideas and to discard old habits that may in fact be a hinderance to their understanding. As a student matures as a Chemistry and/or Physics problem-solver, it may occur that the strategies used in the solution path will become second nature. Students will automatically begin to do those things that will lead them to construct an effective solution to the problem.

In problem solving it is very important that there is no room for misconceptions. Misconceptions resulting from erroneous thinking and wrong information can inhibit success in problem solving (Novak, 1994). As Novak (1994) suggested "teacher should be aware of their own thinking, look for error patterns in student assignments, pay attention to student communications in class, make sure their understanding of the science concept/principle is error free, and when in doubt don't hesitate to refer authoritative books and consult with experts in the field". Additional recommendations from the work of Reddy and Panacharoensawad (2017) include allowing more class time for teacher-guided problem solving practice, and providing summary notes on key topics with examples of solved problems related to those topics.

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