SE-019

THE USE OF EQUATION WORKED EXAMPLES FOR SOLVING ELECTROCHEMISTRY PROBLEM

Erdawati

Dept of Chemistry, State University of Jakarta

ABSTRACT

Equation worked examples emphasize the formation of a coherent problem structure to generate a solution. Its focus is on the construction of three equation steps each of which comprises essential units of relevant information. In an experiment, students were randomly assigned to equation worked examples condition in a regular classroom setting to learn how to solve algebra word problems in a chemistry context. The equation worked examples group out performed for concentration problems, which were more difficult than dilution problems. Quantitative and qualitative analysis, used to assess the changes in the students' problem solving performance, provide some indications that strategy instruction accompanied by strategic supports has a beneficial impact on students' problem solving performance. Implications for problem solving instruction and directions for further research are discussed. Empirical evidence supports the theoretical rationale in using equation worked examples to facilitate students' construction of a coherent problem structure so as to develop problem skills and expertise to solve concentration problems

Keywords *: electrochemistry, problem solving, equation worked example*

INTRODUCTION

A molarity problem such as: "a sample of dolomite is found to contain 0.1 g of sodium hydroxide NaOH , in 200 mL of the solution. Calculate the molarity of the sodium hydroxide in dolomit (= 1, Na = 23, O = 16.00)." is an algebra word problem in a chemistry context. In this problem, H = 1 means the atomic mass of hydrogen (H) is 1.008 g/mole. The molar mass (MM) of sodium hydroxide is the sum of the atomic mass of all elements expressed in g/mole. Hence, the MM of NaOH is: (1× 23 + 1 x 16 + + 1×1 = 40 g/mole. Solving the problem requires operations in algebra. Another sample in 1 mol ion Cu^{+2} containing 2 mol electron because 1 mole Cu^{+2} produced 2 mol electron, and 1 mol electron = 1 Faraday.

According to Mayer (1999), the main hurdle for learning how to solve algebra word problems lies in the learners' ability to discern relevant (problem structure) from irrelevant information (cover stories) in the problem texts, and to make use of the relevant information to formulate a mathematical equation to reach a solution. Indeed, the difficulty faced by many problem solvers is the use of relevant information in algebra word problems to generate, 1992). solutions (Mayer, Lewis, & Hegarty,1995)

In learning to solve algebra word problems, the generation of an equation to represent the problem is crucial (Hegarty, Mayer, & Monk, 1995). An equation provides a skeleton problem structure with ‘slots’ which can be filled in with values and unknown variable and their relations cited in the problem text (Reed & Bolstad, 1991). As such, Cummins (1992) defines problem structure as the quantitative relations among relevant variables expressed in an equation. An equation describing a relation between known and unknown variables is critical to successful problem solving. The importance of depicting the relations among concepts is often emphasized in analogical problem solving approaches. In such approaches, the acquisition of problem solving skills relies on comparing related concepts (known as conceptmapping) across problems, and discarding irrelevant cover stories that may not have direct relevance to the solution (Reed, 1987). It seems that the main focus of instruction for algebra word problems should provide a means to separate the relevant from irrelevant information so that learners will pay attention to the relevant information (problem structure) needed to formulate an equation for the solution. Text editing represents one of these instructions.

Equation Work Example. Reed, Dempster, and Ettinger (1985) found that problem solvers often encountered difficulty in using a learned solution procedure of worked examples to solve a related problem that has a different cover story. In a related study, Chi et al(1989) found that worked examples benefit good students because they tended to deduce solution steps related to the structure of the problem. In contrast, poor students used worked examples to find an equation to which they could ‘slot’ in the values and variables. Therefore, unless worked examples provide a mechanism in enabling students to deduce the problem structure within the solution steps, the effect of worked examples upon learning would be minimal. Indeed, researchers have designed alternative worked examples to overcome the deficiency of worked examples in enhancing problem solving skills. For example, structure-emphasizing worked examples improve students’ performance on categorizing (Quilici & Mayer, 1996) and solving (Quilici & Mayer, 2002) statistical problems more than surface-emphasizing worked examples..

Solving problem in electrochemistry. Electrolysis involves passing an electric current through either a molten saltor anionic solution. The ions are "forced" to undergo either oxidation (at the anode) or reduction (at the cathode). Most electrolysis problems are really stoichiometry problems with the addition of an amount of electric current. The quantities of substances produced or consumed by the electrolysis process is dependent upon the following: electric current measured in amperes or amps, time measured in seconds, and the number of electrons required to produce or consume 1 mole of the substance. Three equations relate these quantities: amperes x time = Coulombs, 96,485 coulombs = 1 Faraday, and 1 Faraday = 1 mole of electrons.

The thought process for interconverting between amperes and moles of electrons is:

amps & time ↔ Coulombs ↔ Faradays ↔ moles of electrons

Use of these equations are illustrated in the following sections.

To determine the quantity of substance either produced or consumed during electrolysis given the time a known current flowed: Write the balanced half-reactions involved, Calculate the number of moles of electrons that were transferred, Calculate the number of moles of substance that was produced/consumed at the electrode, and Convert the moles of substance to desired units of measure.

Equation worked examples. Example 1 shows the design of equation worked examples determine the quantity of substance either produced or consumed during electrolysis given the time a known current flowes. We will describe the former, but not the latter, as they share the same logic. For a quantity of csubstantce problem, an equation worked example involves:

1.Calculate the number of moles of electrons.
2. Calculate the moles of iron and of chlorine produced
3. Calculate the molar mass Fe and volume of chlorine

To calculate the number of moles of electrons, the first step is to write the balanced half-reactions involved. Number of electron calculated based on equation $e = it/F$. The second step is to find the moles of iron and of chlorine produced using the number of moles of electrons calculated and the stoichiometries from the balanced half-reactions. According to the equations, three moles of electrons produce one mole of iron and 2 moles of electrons produce 1 mole of chlorine gas.The third equation step, which contains an integrated problem structure expressed in the form of an equation. mass of iron using the molar mass and calculate the volume of chlorine gas using the ideal gas law ($PV = nRT$).

Example 1: A 40.0 amp current flowed through molten iron(III) chloride for 10.0 hours (36,000 s). Determine the mass of iron and the volume of chlorine gas (measured at 25°C and 1 atm) that is produced during this time.

Solution

Step 1. Calculate the number of moles of electrons.

Write the half-reactions that take place at the anode and at the cathode.

anode (oxidation): $2\,Cl^- \rightarrow Cl_2(g) + 2\,e^-$

cathode (reduction) $Fe^{3+} + 3\,e^- \rightarrow Fe(s)$

Calculate the number of moles of electrons.

$$40.0\text{ amps} \times 36.000\text{s} = 1.44\text{x}10^6\text{s}$$

$$1.44\text{x}10^6\text{s} \times \frac{1F}{96.485} = 14.9\text{ F}$$

$$14.9F = \frac{1\text{ mol e}}{} = 14.9\text{ mol e}$$

1F

Step 2. Calculate the moles of iron and of chlorine produced using the number of moles of electrons calculated and the stoichiometries from the balanced half-reactions. According to the equations, three moles of electrons produce one mole of iron and 2 moles of electrons produce 1 mole of chlorine gas.

$$14.9 \text{ mol e x } \frac{1 \text{ mol Fe}}{3 \text{ mol e}} = 4.97 \text{ mol Fe}$$

$$14.9 \text{ mol e x } \frac{1 \text{ mol } Cl_2}{2 \text{ mol e}} = 7.45 \text{ mol Fe}$$

Step 3. Calculate the mass of iron using the molar mass and calculate the volume of chlorine gas using the ideal gas law ($PV = nRT$).

$$4.97 \text{ mol Fe x } \frac{487 \text{ g Fe}}{1 \text{ mol Fe}} = 278 \text{ g Fe}$$

$$\frac{(7.45 \text{ mol } Cl_2)(0.0821 \text{ atmL/moleK})(298\text{K})}{1 \text{ atm}} = 182 \text{ L } Cl_2$$

Example 2. **Equation worked example.** What current is required to produce 400.0 L of hydrogen gas, measured at STP, from the electrolysis of water in 1 hour (3600 s)?

Example 3. Test problems

Similar test. How long must a 20.0 amp current flow through a solution of $ZnSO_4$ in order to produce 25.00 g of Zn metal.

Transfer test. What current is required to produce 400.0 L of hydrogen gas, measured at STP, from the electrolysis of water in 1 hour (3600 s)?

METHODOLOGY

Sample and design. The experiment involved 28 participants from a open university all taking the same course, The majority of the participants were first year undergraduates A small number of students (9 of them) repeating the course were also participants. The experiment was conducted as part of the course topic on loops and the transfer test was administered as the students' mid semester test. Out of the 30 learners who took part in the experiment, only the data from the 28 learners who completed all the tasks requiredfor the main phases of the experiment were used for the analysis.

Materials. Adapting materials described in general chemistry book, the materials comprised an instruction sheet (example 1), equation worked example (example 2), and test problems (example 3). The instruction sheet included definitions of half reaction, moles of electron and moles of substance. For the equation worked examples, each pair of the acquisition problems (a worked example and a problem) shared an identical problem structure but differed in the assignment of a value or an unknown to each variable (Mayer, 1981).

The test comprised moles of substance problems and two types of items in terms of problem structure (i.e., similar test items and transfer test items). Similar test problems resembled acquisition problems in that they shared a similar problem structure and therefore also a similar solution procedure. There were two types of transfer problems: near-transfer and far-transfer. The near-transfer problems (e.g., drug problem; example 3) were isomorphic to acquisition problems (Reed, 1987) because they shared a similar problem structure but had different story contexts. The far-transfer problems were considerably more difficult than the near-transfer drug problem.

Procedure. The experiment was conducted on two consecutive days during regular chemistry lessons. On the first day, using the instruction sheet as a guide, the chemistry teacher introduced dilution and molarity to all students for 40 min. The aim was to provide the novice learners with pre-requisite knowledge of the concepts related to molarity and dilution, illustrate the mathematical manipulation, and reinforce chemical symbols, atomic mass, molar mass and chemical formulae for solving mass of substance problems.

On the second day, students studied the instruction sheet and completed acquisition and test problems under the supervision of a researcher and the class teacher. Students were told about the procedure of the experiment and asked to read and follow the instructions. No other verbal instructions were given while students completed the tasks in each phase. First, students studied the instruction sheet for 5 min. The aim was to refresh their memories about the definitions and solution procedures of the dilution and molarity problems, which they had studied the previous day. Then, they were randomly assigned to equation worked examples condition with 11 students in each condition.

Equation Worked Examples. First, students studied three sample equation worked examples, which were identical to the text editing sample problems except that each of these contained sufficient information for obtaining a solution. Then they worked on seven pairs of acquisition problems each of which comprised a worked example and a problem. These 14 acquisition problems were a subset of the 20 acquisition problems used in text editing but modified so that each acquisition problem contained sufficient information for obtaining a solution. For each pair of acquisition problems, students studied a worked example and solved a problem. It was anticipated that students would compare each pair of acquisition problems and to transfer the solution procedure depicted in the equation worked examples to solve an equivalent problem that shared a similar problem structure. During the acquisition phase, both groups were matched on time (21 min) to complete as many acquisition problems as they could. Also, they could access the instruction sheet and were free to ask questions. The test phase began immediately after the acquisition phase. Students undertook a similar test (four dilution and five molarity problems) and a transfer test (three dilution and four molarity problems) within 10 min each.

RESULTS AND DISCUSSION

Table 1 shows the means and standard deviations of proportion correct solutions, non-attempted problems, total errors and conceptual errors made in the test phase. One point was allocated for each correct answer. When the students did not attempt a problem, it was considered as a non-attempted problem. Computational errors were ignored. Total errors included conceptual errors, incomplete and obscure solutions. There were two types of conceptual errors depending on whether they were related to chemistry or mathematics. An inaccurate assignment of a value to a variable constitutes a chemical error.

Table 1. Means and (standard deviations) of proportion correct solutions (molarity and dilution), non-attempted problems, total errors and conceptual errors made

No		Equation worked examples N = 34
1	Similar test	Means and sd
	Proportion correct solutions	
	number of moles of electrons	0.64 (0.21)
	moles of iron and of chlorine	0.42 (0.34)
	Molar mas	0.44(0.31)
	Volume gas	0.38(0.28)
	Non-attempted problems	2.87 (1.26)
	Total errors	1.45 (1.04)
	Conceptual errors	1.45 (1.04)
2	Transfer test	
	Proportion correct solutions	
	number of moles of electrons	0.396 (0.10)
	moles of iron and of chlorine	0.45 (0.31)
	Molar mas	0.41(0.33)
	Volume gas	0.38(0.26)
	Non-attempted problems	2.63 (1.29)
	Total errors	1.39 (1.32)
	Conceptual errors	1.31 (1.20)

For example, when students were confused about moles electron (M) and mass of substances (g) – they wrote molar electron = it F with (i =ampere) and t = second and F = 1.On the other hand, a mathematical error occurred if students were unable to convert mole gass to liters (L) and vice versa, or use algebraic transformation skills to solve the equation. The conceptual errors found in this study were mostly chemistry-related rather than mathematical errors. Hence the two types of errors were pooled to provide a single score for conceptual errors.

Similar test. For the similar test, for the significant group effect, a t-test showed that the equation worked examples group out performed the text editing group on moles electron t(28) = 2.00, SE = 0.13, p = 0.05 rather than mles of substance problems t(28) = 0.85, SE = 0.11, p = 0.41. The group ×problem type interaction was not significant, F(1, 20) = 0.96, MSE = 0.08, p = 0.34, _2 = 0.05, observed power = 0.15. A t-test found nonsignificant difference between the two groups on non-attempted problems, t(28) = 0.88, SE = 0.52, p = 0.39; but the text editing group made significantly more total errors than the equation worked examples group, t(28) = 2.00, SE = 0.53, p = 0.05. However, the difference between the two groups on conceptual errors was nonsignificant, t(28) = 1.61, SE = 0.57, p = 0.12 though it was in the predicted direction favoring the equation worked examples group.The test results provided evidence that the equation worked examples group did better in solving similar molarity problems as compared to the text editing group; also, they had fewer total errors than the text editing group. Thus the first hypothesis was supported.

Transfer test. Consistent with the results obtained in the similar test, the equation worked examples group, t(28) = 2.24, SE = 0.61, p = 0.04. The two groups differed neither in conceptual errors made, t(28) = 1.41, SE = 0.58, p = 0.17 nor in non-attempted problems, t(28) = 0.15, SE = 0.59, p = 0.88. Again, the results supported the first hypothesis. The interaction effect between the group and problem type in the transfer test revealed that the equation worked examples group was more competent than the text editing group in solving the conceptually.

CONCLUSION

This study studyied equation worked examples in enhancing learning how to solve moles electron and Moles mass of substance problems. The equation worked examples group generated more correct solutions for moles electron problems (both similar and transfer test), committed fewer errors, and had fewer non-attempted problems than the text editing group. A significant interaction effect on transfer problems revealed that the equation worked examples group was better able to solve structurally similar moles electron problems . For the equation worked examples, the direct guidance in constructing three equation steps explicitly demonstrated a solution procedure that included a coherent problem structure. Students benefited from the guidance to construct each equation step which contains essential units of relevant information, especially the joining of the first and second equation steps to form the third equation step (i.e., an integrated problem structure expressed in a single equation for a solution). In particular, students gained familiarity with the coherent problem structure of molarity problems, and used it not only to solve the molarity test problems in a variety of contexts but also to generate a superior 2-step solution strategy.

REFERENCES

Chi, M., Bassok, M., Lewis, M., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in problem solving. Cognitive Science, 13, 145–182.

Cummins, D. D. (1992). Role of analogical reasoning in the induction of problem categories. Journal of Experimental Psychology: Learning, Memory, and Cognition, 18, 1103–1124.

Hegarty, M., Mayer, R. E., & Monk, C. A. (1995). Comprehension of arithmetic word problems: A comparison of successful and unsuccessful problem solvers.Journal of Educational Psychology, 87, 18–32.

Mayer, R. E. (1999). The promise of educational psychology: Learning in the content areas Upper Saddle River, NJ: Merrill Prentice Hall.

Mayer, R. E., Lewis, A. B., & Hegarty, M. (1995). Mathematical misunderstandings: Qualitative reasoning about quantitative problems. In J. I. D. Campbell (Ed.), The nature and origins of mathematical skills (pp. 137–154). Amsterdam: Elsevier Science Publishers

Quilici, J. L., & Mayer, R. E. (1996). Role of examples in how students learn to categorize statistics word problems. Journal of Educational Psychology, 88,144–161

Quilici, J. L., & Mayer, R. E. (2002). Teaching students to recognize structural similarities between statistics word problems. Applied Cognitive Psychology,16(3), 325–342

Reed, S. K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. Journal of Experimental Psychology: Learning, Memory, and Cognition, 11, 106–125.

Reed, S. K., & Bolstad, C. A. (1991). Use of worked examples and procedures in problem solving. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 753–766.