Teaching solubility through research activities of students in class experiments

Enseñanza de solubilidad en clase a través de actividades de investigación

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Abstract

In this paper, we present an example of teaching and learning solubility (water-oil mixture) through research. Two different types of one-pot consecutive reactions are presented. The first is the electrolysis of water that produces hydroxide ions, which react further to break down the ester linkage of triglycerides that constitute edible oil and to form fatty acid salts. The second is the electrolysis of sodium chloride solution that forms chlorine gas, which reacts further with the double bonds of the unsaturated fatty acyl groups in the triglycerides of the used oil and form a saturated semi-solid oil (a margarine-like substance).

Key words: *teaching, learning, chemistry, experiments, solubility.*

Resumen

Este artículo presenta un ejemplo del proceso de enseñanza y aprendizaje sobre el fenómeno de solubilidad por medio de la metodología de investigación/experimentación. Dos tipos diferentes de reacciones consecutivas serán discutidas aquí. La primera reacción, es la electrólisis del agua, la cual produce iones OH^- que, continúan reaccionando hasta romper enlaces químicos de los triglicéridos que constituyen el aceite comestible para formar sales de ácidos grasos. La segunda es la electrólisis de una solución salina (NaCl) para formar cloro gaseoso el que, continúa reaccionando con el enlace doble del no saturado grupo acílico en los triglicéridos del aceite usado, para formar una sustancia aceitosa semisólida de grasa (similar a la margarina).

Palabras clave: *enseñanza, aprendizaje, química, experimentos, solubilidad.*

Introduction

Science is the outcome of researching scientist work in one stage in his life, even when he was a student and worked under the supervision and the responsibility of the school and the teachers. After all, the teacher is the one who possesses the ability, experience and skills to promote the research and thinking abilities among his students. Thus, the more the teacher invests in his students, the more students' personality and skills will improve as future researchers. The main objectives of the science curriculum are: understanding what is science, scientific methods, comprehension ability, application and improvement of scientific critical thinking and research skills. Knowledge of scientific subjects is very important for the student; it enables him to understand the natural environment that surrounds him. In order to develop the sense of research, it is necessary for the student to carry out scientific experiments in the laboratory. These experiences will provides him with tools to explain the natural phenomena logically and to improve his abilities to think in a scientific manner.

Due the fact that the method adopted by these activities and programs place the child in the center of the learning process, the teacher must be a facilitator and guide. The teacher helps the students to properly define the problem and the questions students wish to investigate, creates a suitable educational climate in the classroom and laboratory, encourages the students to learn and minimize their dependence on him, when facilitating a variety of scientific sources as well as the necessary material and equipment for the children to develop their research and experiments (COLLINS, 2000; COTHRON *et al*., 2000; DUDLEY, 1984; GOODWIN, 2002; HUGERAT *et al*., 2003; IBOLYA *et al*., 2003; SCERRI, 2004; WIERSMA *et al.*, 2004).

The students are the center of the learning process. They must be active involved in designing the experiment, executing it, formulating the questions and searching for answers in order to further develop their natural curiosity..

Through these learning activities and programs, we are trying to establish and develop a methodology to foster a positive attitude on the students about scientific research. The implementation of this methodology includes the following stages:

a. Statement of the problem.
b. Formulating hypotheses.
c. Collecting information through the experiment.
d. Evaluating the results.
e. Drawing conclusions from the experiment.

The main objectives of these learning activities in teaching science are the following:

1. To discover and simplify natural sciences with emphasis on the use of familiar natural material from the child's surrounding.
2. To find a scientific explanation for the natural phenomena in the child's surrounding.
3. To develop the correct scientific thinking in an early age.
4. To promote the child's ability to think scientifically, to ask appropriate questions and to formulate hypotheses.
5. To carry out experiments following scientific procedures.
6. To invoke scientific curiosity and to develop the sense of research and the ability to learn and work among children.
7. To create an opportunity for cooperation and shared work between the student and the teacher.
8. To express opinion freely, to respect the opinions of others, to draw conclusions and to present the subject appropriately.
9. To develop the child's knowledge in making scientific decisions and to describe the relationship between science and other subjects such as language and art.
10. To develop the child's knowledge of solving problems through logical reasoning, to construct a conceptual mapping or a diagram, to summarize what he sees, i.e. the child must be able to organize his thoughts in a specified manner such as a table, a diagram or a summary.

Solubility

When we talk about mixing two or more substances together in a solution we must consider solubility. Simply defined, solubility is the measure of how much solute will dissolve into the solvent. Not all substances will dissolve in all solvents. Understanding its properties will provide a basis for understanding the golden rule of solubility... Like dissolves like! All liquids are not alike. When a liquid such as the food coloring dissolves in another liquid, the two liquids are called miscible. When two liquids such as oil and water do not mix or dissolve, they are called immiscible. Upon stirring or shaking an immiscible solution, sometimes tiny droplets will form throughout the mixture. These are called emulsions, but when stop stirring, the liquids will separate again, for example, the oil will collect above the water. This occurs because the oil is lighter, or not as dense, as the water. Since the water molecules are heavier than oil, they all sink to the bottom (BLAKE, 2003, HARLE *et al*., 2003, LETCHER, 2001).

The polarity of the solute and solvent molecules affects the solubility. Generally polar solute molecules will dissolve in polar solvents and non-polar solute molecules will dissolve in non-polar solvents. The polar solute molecules have a positive and a negative end to the molecule. If the solvent molecule is also polar, then positive ends of the solvent molecules will attract negative ends of the solute molecules. This is a type of intermolecular force known as dipole-dipole interaction. All molecules also have a type of intermolecular force weaker than the other forces called London Dispersion forces, where the positive nuclei of the atoms of the solute molecule will attract the negative electrons of the atoms of the solvent molecule. This gives the non-polar solvent a chance to dissolve the solute molecules (BLAKE, 2003; HARLE *et al*., 2003; LETCHER, 2001; PRAVIA, 1996; SILVERSTEIN, 1998).

ORGANIZING OF STUDENTS EXPERIMENTATIONS

When the subject of solubility and water transparency is taught in high School, using the method of scientific thinking and learning by discovery, the following steps are implemented. (HUGERAT *et al*., 2001, 2003, 2004):

1. Feeling the problem:

The teacher introduces the subject of solubility and water transparency to the class in the form of an open question. For example:

- "Have you ever drank a clear liquid thinking it was water?"
- "Have you heard that one of your friends had drank a liquid that looked like water, and was then taken to the hospital?"
- "What would happen to you if you drank a dangerous liquid that looks like water?"
- "Is oil soluble with water?"
- "What can we do to make oil and water dissolve?"

2. Statement of the problem:

The teacher raises a group of questions. The answers to such questions constitute the path for the solution of the problem. For example:

- What is the significance of water in our daily life?
- What is the chemical structure of water?
- What happens when we mix water and oil together? Why?
- What are the different methods that show that transparent water is quite different from the other transparent liquids?
- Can you state the constant relation between water and other transparent liquids?

3. Data collection:

Under the teacher's guidance, the students' carryout experiments, review literature, and watch educational movies.

4. Hypotheses formulation:

1. Water is significant in all different aspects of our life.
2. Water is composed from the two important elements, Oxygen and Hydrogen.
3. Water is a transparent liquid, but it is different from all other transparent liquids that may look like it.
4. There are several methods to show that the chemical behavior of the transparent liquids is different.
5. A mixture of water and oil are not soluble.

5. Hypotheses Testing

With the help of their teacher, students examine their hypotheses by carrying out experiments. They reject the erroneous hypotheses. Watching educational movies and reading scientific journals may help in testing the hypotheses. Teachers may help their students to develop the necessary skills to operate laboratory equipments, to carryout experiments in a scientific manner, and how to express their findings in a scientific manner.

6. Generalization

1. Water is significant in our daily life. Plants and animals cannot survive without water. Plants are very essential in human life, especially in their role in photosynthesis.
2. Unlike other transparent liquids, water is composed of two important elements, Oxygen and Hydrogen on the rate of 2:1 Hydrogen to Oxygen (H_2O). Oxygen is essential for breathing and Hydrogen for good fuel.
3. Acidity wise, water is a balanced compound. This is unlike the other transparent liquids; they are either acidic or basic compounds in nature.
4. Unlike other transparent liquids such as Hexane, water is considered a universal solvent.
5. According to the above and based on learning by discovery, we reached one of the most widespread rules: "Not every transparent liquid is water".

EXPERIMENTS

Solubility and water transparency

These suggested experiments based on this method summarize the material of organic and inorganic chemistry for high school (14-15 years of age). During these experiments, the student connects between two subjects he had studied previously (electrolysis and organic reactions). These experiments are carried out when students work in small groups (3-4 students) where every participant has a role.

Hazards

For safety reasons, the teachers and the students should adopt the following basic safety precautions:

1. Avoid tasting and inhaling the vapors from any of the used materials. Avoid contact with the chemicals and keep them in a safe place away from the combustion site.
2. Wear gloves and safety goggles.
3. While conducting the experiments, the room should be open for ventilation. Keep all chemicals and solvents in the hood except when they are being directly used under supervision.
4. The students should avoid contact with the electric coils, although with the low-voltage devices there is no possibility of electric shock.
5. Experiments in which will be released Cl_2 and Br_2 must be conducted in the hood.

Experiment 1:

1. Prepare three glasses. Fill one with glycerol (purity of 99%), one with *n*-hexane and one with ethanol. Students observe that there are three transparent liquids, each in a separate glass. Since all glasses look the same externally, students will infer that all the glasses contain the same liquid. The teacher asks the students to add gently a similar volume of water to each glasses (not shaking the glasses and also not leaving the mixture for more than few hours, because glycerol and water are miscible in all proportions). The student will observe different behaviors for the three liquids. This occurs basically because the different miscibility and density of the substances. In a second step, the teacher asks the students to add a similar volume of seed oil (corn oil or sunflower oil) or olive oil to each glass. The students observe that the three transparent liquids behave differently when water is added in the first step and also when seed oil is added in the second step (HUGERAT *et al*., 2001, 2003, 2004). If the glasses are kept overnight it can be observed that water and glycerol form one phase in glass A because water and glycerol are miscible in all proportions.
2. Prepare three glasses. Fill one with glycerol (purity of 99%), and one with paraffin oil and one with water (Fig. 1). Students observe that there are three transparent liquids, each in a separate glass. Since all glasses look the same externally, students will infer that they all contain the same liquid. The teacher asks the student to add gently a similar volume of red cabbage juice to each glasses (not shaking the glasses and also not leaving the mixture for more than few hours, because glycerol and water of the red cabbage juice are miscible in all proportions). The student will observe different behaviors for the three liquids basically because of their differing miscibility and density. If the glasses are kept overnight it can be observed that red cabbage juice and glycerol form one phase because the water of the red cabbage juice and glycerol are miscible in all proportions (HUGERAT *et al*., 2001, 2003, 2004).

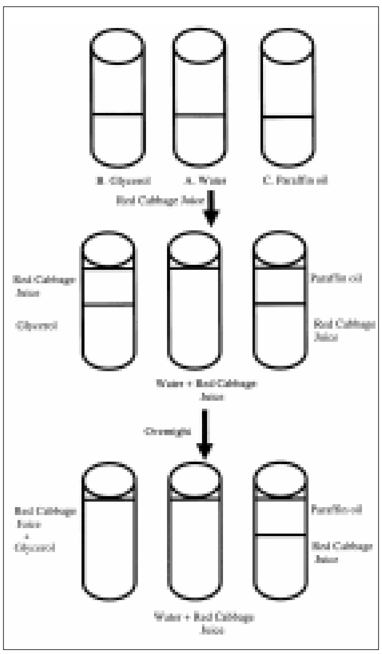


Figure 1. Three glasses contain glycerol, water and paraffin oil. The student adds gently a similar volume of red cabbage juice to each glass and leaves the mixture overnight.

Experiment 2:

a. Add tap water to the Hoffman Apparatus (Fig. 2). Connect both negative and positive electrodes to a 9V battery. Notice the immediate appearance of bubbles around the electrodes. Notice also that the amount of bubbles around the negative electrode is twice as large that around the positive one.

b. Repeat the experiment by adding *n*-hexane, a transparent liquid. Notice that there is nothing happening on the electrodes.

c. Repeat the experiment by adding paraffin oil, a transparent liquid. Notice that there is nothing happening on the electrodes.

d. Repeat the experiment by adding olive oil. Notice that there is nothing happening on the electrodes.

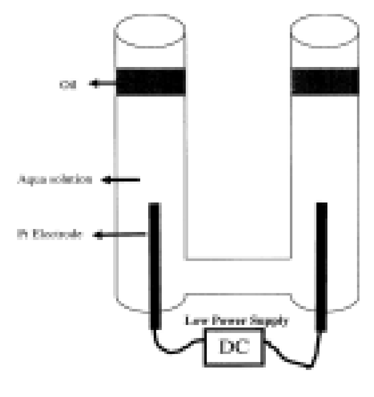


Figure 2. Hoffman apparatus. Dimensions: The height of each glass cylinder is 13 cm and 1.5 cm in diameter. A power supply for 12 volts.

Experiment 3:

Solubility in Biphase Systems:

In salty water electrolysis reactions, chlorine gas, hydrogen gas, hydroxide and hydrogen ions are among the most familiar species to be produced. Also, saponification of oils and fats under alkaline conditions is one of the most common lab activities for high school as well as college students. In these consecutive reactions, the ester linkages in oils and fats are hydrolyzed to produce glycerol and salts of long-chain carboxylic acids that form soap (HUGERAT, 2004).

Consecutive reactions are simply defined as two reactions or more proceeding in one pot, where the products of the first reaction are used in a following reaction. The literature that deals with this type of reactions, describes consecutive reactions in a one-phase system where substrates and products are in direct contact with each other in the reaction medium (HUGERAT *et al*., 2004).

The main advantages of the Solubility in Bi-phase Systems experiment are:

1. The bi-phase system facilitate the generation of a visual process consecutive reactions are taking place.
2. Controlling the identity of the aqueous solution affects the identity of the products.
3. Demonstrate reactivity differences between H_2, O_2, Cl_2 and Br_2 with alkenes and other unsaturated organic compounds.
4. Facilitate the understanding of the hydrophobic-hydrophilic characteristics of different compounds and their solubility in aqueous and organic medium.

Experimental procedure: An aqueous solution (30 ml of 1 M NaCl, 1 M HCl, 1 M NaBr, 1 M Na_2SO_4, or 1 M H_2SO_4) is placed in a Hoffman apparatus. Unsaturated oil (2 ml of sunflower or soybean oil) is added on top of the aqueous solution on both sides of the apparatus resulting in a two-phase system in both half-cells (Fig. 2). Wait until any emulsion that might form disappears and the two-phase system is easily distinguished before running any current through the cell. Connect the Hoffman apparatus to a low power supply (e.g. 12VDC) and allow the current to flow until a significant reaction is observed at the oil/water interface (typically, 5-10 min).

In the aforementioned experiments, we have seen that employing the most familiar produced species in electrolysis reactions, such as chlorine gas and hydroxide ions (HEIDEMAN, 1986; HENDRICKS, 1982; HUGERAT *et al*., 2004; WARD, 1987; ZHOU, 1996), and consuming them as substrates in a consecutive reaction, such as additions to double bonds and base-catalyzed hydrolysis reactions for oil triglycerides, respectively, they serve as very helpful examples for students to understand and observe this type of reaction sequence (ADAM, 1998, HUHEEY *et. al.*, 2002). For instance, chlorine molecules, which are produced at the anode (HUGERAT *et al*., 2004),

$$2Cl^-_{(aq)} \longrightarrow Cl_{2(g)} + 2e^- \quad \text{(At the anode)}$$

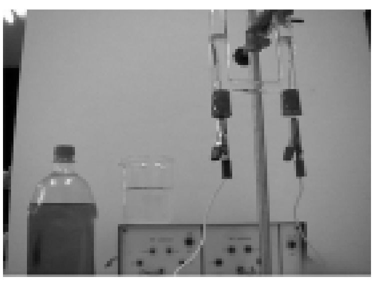
can react in a consecutive addition reaction with a carbon-carbon double bond of an organic substance, such as unsaturated liquid oil that covers the surface of a water solution in the electrolysis system (see Fig. 2) (HUGERAT *et al*., 2001).

$$\begin{array}{l} CH_2\text{-}O\text{-}CO(CH_2)nCH{=}CH(CH_2)mCH_3 \\ | \\ CH\text{-}O\text{-}CO(CH_2)nCH{=}CH(CH_2)mCH_3 \\ | \\ CH_2\text{-}O\text{-}CO(CH_2)nCH{=}CH(CH_2)mCH_3 \end{array} + Cl_2 \longrightarrow \begin{array}{l} CH_2\text{-}O\text{-}CO(CH_2)nCHCl\text{-}CHCl(CH_2)mCH_3 \\ | \\ CH_2\text{-}O\text{-}CO(CH_2)nCH{=}CH(CH_2)mCH_3 \\ | \\ CH_2\text{-}O\text{-}CO(CH_2)nCH{=}CH(CH_2)mCH_3 \end{array}$$

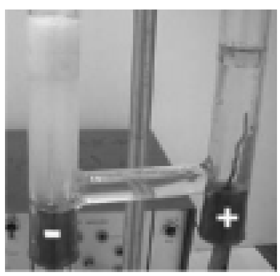
(Unsaturated oil triglycerides) (Partially saturated oil triglycerides)

This additional reaction between chlorine and the liquid oil produces a partially saturated semi-solid oil; a margarine-like substance, that can be clearly observed in the water-oil interface. Under these conditions, hydrogen gas is less electrophilic than chlorine or hydroxide ions, therefore when produced in the electrolysis system it does not attack neither the double bonds nor the ester linkages of the unsaturated triglycerides in a consecutive reaction. Similar results to those obtained in the NaCl system were also obtained when using a solution of NaBr, where, the generated bromine in the electrolysis process, which is distinguished with its brown-red color, could be visually seen disappearing due to its consumption in a consecutive reaction with the double bonds of the oil triglycerides to form the margarine-like substance.

Furthermore, when hydroxide ions are produced in an electrolysis reaction they attack the ester linkages of triglyceride molecules that constitute the oil and result in producing fatty acid salts (soap) that can be observed as foam on top of the liquid oil in the electrolysis system (Fig. 3). It can be clearly seen from the observed results after a few minutes of electrolysis, the oil phase starts to react in the cathode half-cell in the experiments where the salt solutions of NaCl, NaBr and Na_2SO_4 were separately electrolyzed. As a result of this reaction, fatty acid salts (soap foam) start to appear and accumulate with time on top of the cathode cell (Fig. 3). These changes that occur in the NaCl, NaBr and Na_2SO_4 systems are attributed to the production of hydroxyl ions (OH^-) at the cathode,



A



B

C

Figure 3. Hoffman apparatus with two-phase system (water and oil) in the cathode we observed foam of fatty acid salts and in the anode we observed margarine-like substance.

$$2H_2O_{(l)} + 2e^- \longrightarrow H_{2(g)} + 2OH^-_{(aq)} \quad \text{(At the cathode)}$$

Which consecutively break down the ester linkages of the oil triglycerides to yield fatty acid salts and glycerol (Fig. 3). The hydrolysis of the oil triglycerides with the hydroxide ions generated in the cathode half-cell is described in the following equation:

$$\begin{array}{l} CH_2\text{-}O\text{-}COR \\ | \\ CH\text{-}O\text{-}COR \\ | \\ CH_2\text{-}O\text{-}COR \end{array} + 3NaOH \xrightarrow{H_2O} \begin{array}{l} CH_2\text{-}OH \\ | \\ CH\text{-}OH \\ | \\ CH_2OH \end{array} + 3RCOONa$$

(Oil triglycerides) (Glycerol) (Fatty acid salts)

Where, R is a fatty acyl group.

Pedagogical observations

Carrying out this experiment with the presented methodology has a positive impact on the class climate according to anecdotal references from the instructors. This appeared clearly in the students' grades, from one side, and also their positive appreciation and attitude towards the chemistry lessons, on the other. The suggested methodology has many advantages such as:

1. The student is the focus of the educational effort. It allows him to participate actively in planning the task and execute it. In this method, the teacher is not the only source of information. He introduces a problem through a discussion and leave for the students to investigate possible solutions and design an experiment under his guidance.
2. The teaching material is flexible and variable rather than specific and predetermined. This helps the cooperative work in heterogeneous groups.
3. Different students work in different tasks at the same time based on their abilities, tendencies and way of learning. Following the teacher's introduction of the problem for the groups, the students begin to design the experiment. As they start the execution, every student starts to work according to his own method with the consensus of all member of the group.
4. This method showed real interaction between the students. This led to the creation of an environment of cooperation and positive competition. We observed clearly that the learning climate has changed completely during the activities. As a result, the students requested more similar activities. Regarding the request of our students, we are changing the curriculum to incorporate more activities based on this methodology.
5. The textbook is not the only source of knowledge. Students resort to other sources. We noticed during the experiment "Solubility in Biphase Systems" that the students used computers in order to find information about reactions of the hydroxide ion with oil after they found out that one of products of the electrolysis is the hydroxide ion. In this method, they were able to analyze the results of the reactions.

This method has also disadvantages such as working in group needs preparation ahead of time; the students are not active all the time and there is a possibility for chaos and loss of control in the classroom. Therefore, teachers have to work harder in order to prepare for this method prior to starting the experiment.

Research shows that teaching scientific material without the pupils' active participation in the experiment and research make the learning process insignificant. There are many chemical and physical methods to demonstrate solubility of water and oil. Some of these methods have been presented in this article. From these experiments the students learn that "apparently" similar materials may have "hidden" differences and that phenomenon can be investigated using different chemical and physical approaches. Students that have conducted theses experiments in our classes have been excited and enjoyed the learning process. This method contributes to generate a positive learning environment in the school, increasing the motivation of the students to be in class.

CONCLUSIONS

In this paper, we presented several examples of teaching and learning solubility through research. There are several methods to show that the chemical behavior of the transparent liquids is different. In this article we present a method where the students test their hypotheses by carrying out experiments with the help of their teacher. One of the examples included the implementation of the learning process of teaching solubility through research activities with a two consecutive reactions experiment. The impact of this methodology on the students was positive and motivates the incorporation of more activities like the presented in the paper in the curriculum. Although this experience was positive, there is a need to more research in this topic to validate the use of research activities in lower levels

AKNOWLEDGMENT

This project has the corresponding support of the Academic Arab College for Education, Haifa, Israel and the Pontificia Universidad Javeriana, Bogotá, Colombia

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Received: 10.11.2006
Approved: 29.09.2007