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Teaching Electrolysis in High School and College—A Comparative Research

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Abstract

This paper presents a comparative research between high school and college students, regarding the basic concepts of electrolysis. The importance of electrolysis as a crossroad between sciences, and as essential for understanding the causes of electricity and the influence on technology, is emphasized. The results showed a significant difference between the pre-test and the post-tests. The achievements of the college students were higher than those of the high school, however some of the difficulties observed in the high school still exist to some extent in the college. This paper argues that the history of science can be a useful and fruitful inspiration to science teaching.

Keywords

electrolysis, High-school, college

1. Introduction

This manuscript is a continuation of a previous paper, in which we described the effect of the instruction of electrolysis, composed of hand on experiences complimented by class discussions (Bar et al., 2016). The instruction was done among a group of high achieving and motivated high school girls aged 16. The instruction affected a significant improvement of results between the pre-test and the post-test stages. Many difficulties were still observed at the post-test stage. Most of those difficulties were already recognized by previous research. A t-test measure differentiated between the numbers of the wrong and the right answers at the post-test stage was insignificant.

In light of the results of the previous research, we decided to carry out a similar research in a group of college students. The instruction and research took place within their Chemistry course. This was done to enable us to measure the effects of maturity and more knowledge on the understanding of elementary electrolysis among the college students, comparing to the high school girls. The experiment is not a controlled experiment since two variables are mixed in the comparison, but it might give some clues to the improved result. The present paper contains two parts: first, an evaluation of the results of the test among the college students in pre-test and post-test stages; second, a comparison between former results of high school and the college students (Bar et al., 2016). An estimation of the causes of that improvement are presented. According to the results of both parts, a suggestion for further improvement of the instruction and its results is also presented.

2. Historical Background

To establish the importance of the electrolysis among the sciences we shall give a historical survey of the development of the scientific field of electricity, from the discovery of its motion (Gray, 1729), through the development of electrolysis and further findings in electricity and its applications, up to 1830 (Park, 1989).

2.1 Electrostatic and the Discovery of Electrodynamics

Electricity as electrostatic was reported at 600 BC by Thales of Malthus based on earlier observations of a mysterious force exerted on sheep when their wool was rubbed, and caused light materials to move against falling direction (Park, 1989). The same basic idea prevailed up to the 18th century in spite of better knowledge of materials and modes of rubbing, such as using spinning spheres instead of rubbing by hand. This use was repeated in modern physics in the research of elementary particles (Ne'Eman & Kirsh, 1996). During this period, materials were classified to those that can be electrified and those that cannot. Besides electrostatics, the magneto-static force was also observed, and used for navigation. It was Gilbert (in his monumental book *the magnet*, 1600), who suggested distinguishing between magneto-statics and electrostatics, based on the following differences, which can be experienced even today at the elementary school (in spite of developments in knowledge that limit some of them).

Table 1. Magnetism Vs. Electricity According to Gilbert

Magnetism	Electricity
Can be applied to Iron and loadstone alone	Acts on many materials
Act thorough water	Extinguished by humidity
Permanent	Temporary
Not activated by rubbing	Activated by rubbing

Some of the claims of Gilbert are not admissible today, probably due to inferior knowledge and technology at his time. First, Gilbert did not know the elements Cobalt and Nickel, which together with Iron are the three magnetic elements. Second, while the loadstone is a permanent magnet, and modern artificial magnets stable for quite long time, the electrostatic force disappears in a short time. Third, like electricity, magnetism can be activated by rubbing when steel is used instead of "soft" iron. When some of Gilbert's statements are corrected according the modern knowledge, experiences could be made in the class in order to distinguish between electrostatics and magneto-statics. The main effect that still differentiates between the two is the fact that magnetic force acts through water but the electrostatic force does not, and stops by humidity. This point will be discussed in our curricular suggestion.

The understanding that electricity can move from one place to another was made public by Stephen Gray (1666-1736). He discovered that the electric effect could be made stronger by using more advanced technology: rubbing materials against spinning spheres or wheels of sulfur, wax, glass, or rubber (Gray, 1720, 1731). The view of electricity as nothing more than electrostatics was challenged during the first half of the 18th century. In order to find the extent of the effect of the exerted force, Gray conducted experiments using different lengthens of wires. When his wire was too long to be held, Gray hanged his wire on the ceiling using a copper wire, and observed that the electrical effect stopped. Unfortunately, Gray still used the old classification scheme differentiating between materials that can be electrified, and those that cannot. We may speculate that the very use of copper by Gray was due to "its being a matter that cannot be electrified" according to the old classification (Gray, 1731), and hence will not interfere with his experiments. When found that the effect of electric motion was distinguished, he explained his observations by saying that materials that cannot be electrified like Copper "kills" the electricity.

Charles Francois du Fay (1698-1739, 1734) extended Gray's discoveries, based on Gray's findings, and suggested a new classification system. Instead of classifying materials as those that can or cannot be electrified, du Fay suggested the terms "conductors" and "isolators" for those materials that allowed electricity to pass through them, and those that did not.

Du Fay suggested that all materials could be electrified and recognized that non-electrics (today's-insulators) could be strongly electrified, and conducting materials can be electrified when isolated from other conductors. Furthermore, du Fay argued that an isolator could conduct electricity if the electric force is strong enough or the distance is small (1734). These findings inspired two important inventions: the electroscope, invented by Abraham Bennet in 1787 (Derry & Williams, 1960), and the Leyden jar, invented separately by both Kleist and Musschenbroek in 1745 (Hackmann, 1978). The electroscope consists of an isolated metal rod and thin metal leaf that moves when the device is electrically charged, demonstrating that an insulator can exert an electrostatic force, and the conductor can deliverit and being affected by it. The displacement of the leaf is proportional to the strength of the electric charge, so it is used as a charge-measuring device. The Leyden jar is a device that can separate a strong electric charge. In the United States, Benjamin Franklin (1706-1790) used a kite to channel a tiny fraction of the energy from a lightning bolt to a Leyden jar. In order to confirm his hypothesis that lightning is indeed an open circuit electric current, akin to a spark that passes between two charged objects.

Du Fay, who still measured electrification by attraction and repulsion, had observed that some materials tend to attract, and some tend to repel, other materials. He interpreted it as evidence for the existence of two distinct kinds of electricity, *vitreous* (glass) and *resinous* (amber), later renamed *positive* and *negative* (Du-Fay, 1730; he noted this "as his best discovery"). Furthermore, du Fay also realized the different roles of copper and silk in Gray's experiments, and suggested that the Copper did not kill the electricity but conducted it to the ceiling where it spread, and the electrostatic force diminished. Du Fay ideas and explanations are very fruitful and paved the way to later developments. To sum, Charles Françoisdu Fay (1734) changed the classification system to *conductors* and *non-conductors*, and explained Gray's observations according to his new classification scheme. This new classification can be used to explain the lightning discharge when air is humid and strengthen Franklin theory about the lightning. Du Fay also claimed that any matter can be electrified, if it is isolated from the environment, by a non-conductor (this and fact that similar kinds of electricity repel each other is the base of the operation of the electroscope); and that electricity may move in non-conductor if the electric force is strong enough. These ideas made his interpretation more fruitful and induced a conceptual change (Posner et al., 1982) that paved the way many ideas to follow.

2.2 Electrolysis and Technological Uses of Electricity

Although the development of ideas about electrostatics was an important intellectual achievement, it took time for them to be translated into fruitful technological solutions to meet human needs. The beginning of modern electricity can be stated to the year 1791, with Luigi Galvani's observation of a shock that occurred to a frog leg held by two metals (Whittaker, 1951). Galvani interpreted this observation as a special property of living bodies: "animal electricity". The electric conductivity of humans and animals was known at the time by the public presentations of Gray in which electricity was applied to a human held by non-conducting ropes (Figure 1); in these demonstrations, electricity was applied at one place, and electric sparks where observed at various other points, emitted from the body.

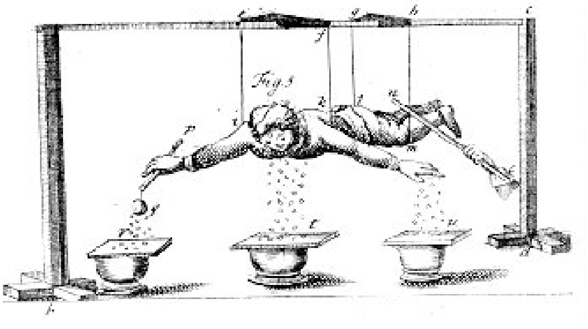

Figure 1. The Effect of Electricity Is Observed away from Its Source

The first step in the direction of the practical use of electricity was Allesandro Volta's (1745-1827) invention-the battery. Volta's invention owes much to the famous experiment by Luigi Galvani (1737-1798, Figure 2), which Volta had replicated and came to believe that the different metals used for the hooks and the tissue of the frog's legs caused the muscles to twitch.

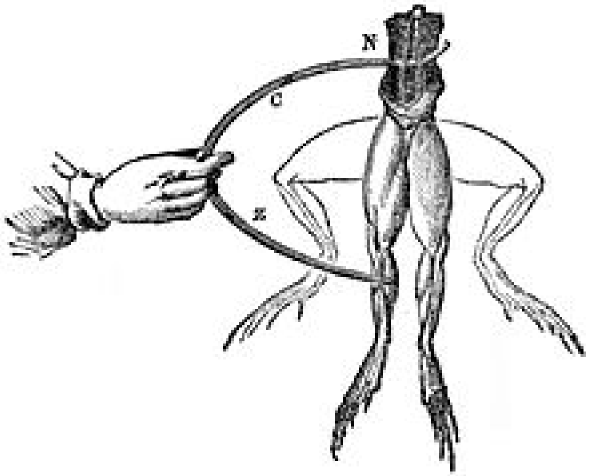

Figure 2. Galvani Experiment: Two Metals Attached to the Frog Cause Muscles to Twitch

That led Volta to experiment with a "sandwich" of two different metals with brine-soaked cardboard (instead of frog's legs) separating them. When the metals were connected by a conductor, an electric current passed through the conductor, and thus the first battery was created (Figure 3). Later, Volta added more layers of cardboard and metal plates, creating a *voltaic pile* (Figure 4), which opened a floodgate of research and invention. A notable example is William Nicholson (1753-1815) and Anthony Carlisle (1768-1840) use of the battery to split water into Hydrogen and Oxygen.

The next monumental step in the research and application of electricity was when Davy and Faraday visited Volta in Milan. Volta, impressed by "these two young and bright scientists" (Faraday museum London, 1778) gave them his original pile as a gift. Humphrey Davy (1778-1829) enhanced the voltaic pile and used a powerful voltaic pile to discover a series of new chemical elements: the alkaline metals and the metals that resemble Calcium. Davy also used his voltaic pile to produce the first electric light by inserting two pieces of carbon into the circuit and moving them apart so they almost touched each other.

2.3 Electrolysis-Theoretical Background

To clarify our ideas and curricular suggestions we shall present a description of the theoretical background of the domain of electrolysis, with some of its present technological applications and other domains related to it.

As mentioned, the discoveries and inventions that followed Volta (1800) and Galva*ni* (Whittaker, 1951) were adopted in the experiments of Davy, who enhanced the pile and used it to extract metals from their compounds. These applications bridged physics, chemistry and technology, as electrochemistry.

Ions. The main concept used in electrochemistry is the *ion*-electrically charged particle in aqueous solution, as a carrier of electricity in these solutions (The present meaning of the ion is an atom or a molecule in which one or more electrons are missing or with one or more additional electrons). The idea of the moving charge starts with the English physicist and chemist Michael Faraday (1834). Faraday did not knew the nature of these species, but he knew that metals dissolved into, and entered the, solution at

one electrode, and metal emerged from the solution at the other electrode. He assumed that some kind of substance moved through the solution in a current when attached to the electric source, conveying matter from one place to the other and called the matter *ions* (The word *ion* is the Greek ἰόν, "going", that contains the present participle of ἰέναι, *ienai*, "to go"). Faraday also introduced the words *anion* for a negatively charged ion, and *cation* for a positively charged one. In Faraday's nomenclature, cations were named so because they were attracted to the cathode in a galvanic device and anions were named due to their attraction to the anode. Since ions carry charge, they are influenced by an electric field and can move in it. This definition is related to the structure of the atom as found later by Ernest Rutherford (1911) and Niels Bohr (1913) in the 20th century. Ions have a role in both the battery and in the electrolysis cell.
The battery, as invented by Volta, was made out of two different metals (Early practical batteries used Copper and Zinc as electrodes), and a conducting solution between them, as shown in Figure 3.

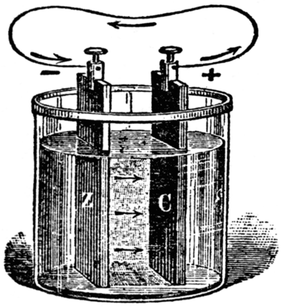

Figure 3. Volta Battery, a Photo of Volta Cell, Current Direction is from + to -; Electrons Move from - to +

In later batteries, the Copper was replaced by coal, and an oxidizing agent added to absorb the emitted Hydrogen that may reduce the activity of the cell. The conducting fluid was inserted into powder in order to create the "solid cell". Modern batteries contain Lithium instead of Zinc, in order to create a higher reduction potential (The reduction potential is the tendency of the electrode to give or to accept electrons and become an ion, positive or negative). Note that the signs of the electrodes of the battery are related to the reduction potentials of the electrodes: the negative electrode sends more electrons to the conducting wires. Notwithstanding these changes in the battery, the basic structure suggested by Volta and used by Davy is still being used at our time. This basic structure allows the battery to extend the separation of charges created by rubbing, i.e., to convert chemical energy into electrical potential energy, when static electric force was created between the electrodes.
The opposite process is exemplified by the current generated by the battery and used in the electrolysis cell, producing chemical energy. As mentioned, the earliest electrolysis cell was a non-conductive container filled with a conducting liquid, in which both the positive and the negative electrodes were inserted, as demonstrated in Figure 4:

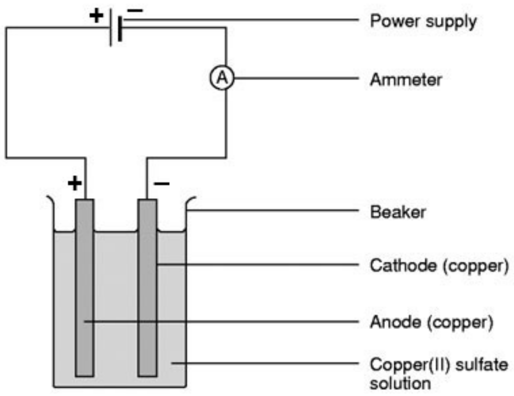

Figure 4. Early Electrolysis Cell

The modern cell is divided into two **half-cells**, one for the positive electrode and one for the negative electrode. A tube that contains the electrolytic liquid connects the half-cells, thus the compounds which are being generated near the electrodes do not mix.

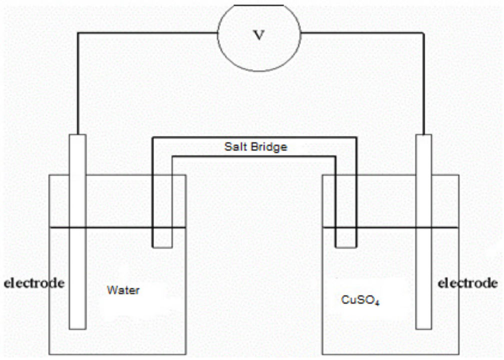

Figure 5. Advanced (Modern) Electrolysis Cell

The same technology is also being used in the modern battery (Figure 6), separated into two half-cells connected by a salt bridge:

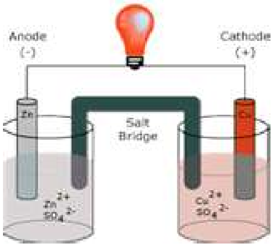

Figure 6. Advanced Galvani Cell, a Battery Containing a Bridge

In order to extract the current from the battery, the two electrodes of the battery are connected to conducting metal wires. These current conducting devices are connected to the electrodes of the electrolysis cell, or to other electric devices (e.g., a bulb). The efficiency of the batteries depends on the difference between the reductions potentials of the metals used as electrodes. While electrons move in the wires, the current is carried in the solution by two currents of ions moving in opposite directions. Reduction potentials are measured relative to a hydrogen electrode, which reduction potential is regarded as zero. Accordingly, the voltage of a battery is measured by subtracting or adding the two half-cells reduction potentials.

These structures embody the connection of these devices to physics, chemistry and technology. The ideas about the structure of the atom and the ion are physics related. The connection to chemistry is due to Faraday's laws (1834), especially to his second law, which connects the electricity to the chemical concept of the valence.

According to Faraday's first law, the amount of matter extracted on each electrode of the cell is proportional to the amount of electricity that moved in the cell: $Q=IT$ (I current intensity, T the time). According to his second law, in a set of cells connected in series (with the same current flowing in them, as was formally noted by Kirchhoffin, 1845), the amount of matter exerted in each cell is proportional to the atomic-molecular masses divided by the valences of the materials. Formulating these laws and giving a more general classification of conductors and isolators (non-conductors), are among the reasons Faraday is considered as the leading light of electrolysis.

Many contemporary technologies rely on electrolysis (e.g., electro plating; advances in the design of batteries and accumulators; cleaning water; anodization of metals to reduce corrosion, production of oxygen for spacecrafts and nuclear submarines, and extracting hydrogen as fuel). The uses of electrolysis are of high importance to environmental sciences, as a key factor to water cleaning, and nutrition (e.g., the making of saturated fats).

These modern applications serves as another justification to the instruction of electrolysis to high school and college students, since they emphasize the relevance of electrolysis curriculum to the philosophy of STSE (science, technology, society and the environment. Aikenhead, 2003), and SSI philosophy: social decisions as part of the science teaching (Tobin et al., 2011). Our research uses ideas taken from the history of chemistry and physics in order to impart knowledge of electrochemistry, and exemplify its technological uses. In the concluding discussion, we will emphasize the debates between the leading figures that took place in the described research; debates that lead to the progress in the domain.

3. Students' Alternative Conceptions Regarding the Electrochemical Cell

Previous research suggests that students enter chemistry classes (or other sciences) with pre-conceived ideas about the natural world (Duit, 2009; Wandersee et al., 1994). These ideas lead students to make predictions and provide explanations that may differ from currently accepted scientific conceptions, called alternative conceptions (Herron & Nurrenbern, 1999). This research accepts the assumption that learning occurs by construction of knowledge in the mind of the learner (Bodner, 1986); when the learner tries to assimilate new information into his or her existing knowledge structure, former ideas may affect this process. Hence, the instructional process described in this paper commenced with observing the students' initial conceptions and knowledge regarding electrolysis. Knowing these conceptions is crucial for affecting a conceptual change among the participants, and enhance their understanding.

Previous research found that electrochemistry is especially difficult subject for the student, possibly since many prior alternative concepts can be traced among their ideas (Driver & Oldham, 1986). It is important to state that many of these misconceptions are found in the different stages of the history of the research electricity described above, thus the study of history of this subject can be a useful tool for teaching. Some of the misconception are described in the following paragraphs.

Allsop and George (1982) stated that students had difficulty in producing scientifically accepted ideas concerning electrochemical cells, understanding both batteries and electrolysis cells diagrams, and in predicting the cell's reactions. Ogude and Bradley (1994) reported pre-college and college students believed that electrons flow through the salt bridge and in the electrolyte solutions. They also stated incorrect direction for the movement of either electrons or ions. This problem is basic to the discipline; metals conduct electricity due to free electrons that exist in them, but there is no movement in the opposite direction (electrons are much lighter than the rest of the atoms, which hardly move). The battery and the electrolytic cell are both based on separation between positive and negative electric ions in water solutions, and opposite motions of them as bi-directional currents. Metals stop their functioning since they do not allow bi-directional motions of charged ions. In another article, Ogude and Bradley (1996) identified students' difficulties regarding to aspects of cell components, cell EMF's, current, electrode processes and terminology. The results suggested that many students believed that electrodes of the electrolysis cell were pre charged (as those of the battery). In another research, Garnett and Treagust (1992) conducted interviews with high school students, and reported six areas of conceptual difficulties that students had about electrolytic and galvanic cells (which received special attention within our research):

(a) Identifying the anode and cathode in electrolysis cell.
(b) The need for a standard half-cell.
(c) Current in battery and electrolysis cell.
(d) The charge of the anode and cathode in battery cells.
(e) Identifying the anode and cathode in electrolysis cells.
(f) Predicting the products of electrolysis and the magnitude of the applied EMF between the electrodes.

Sanger and Greenbowe (1997) replicated Garnett and Treagust's interviews (1992) on batteries and electrolysis cells and extended them to concentration cells, and detected further alternative conceptions among the students. Students thought that electrons flow through the electrolyte solutions in the salt bridge in order to complete the circuit. The students also thought that the plus and minus signs assigned to the electrodes represent net electronic charges, and that water is not reactive in the electrolysis of aqueous solutions. In addition to the alternative conceptions identified in Garnett and Treagust's study (1992), Sanger and Greenbowe (1997) reported other students' notions including the beliefs that half-cell potentials are absolute and can be used to predict the spontaneity of individual half-cell reactions, and that electrochemical cell potentials are independent of ion concentrations. More recent Research reported similar difficulties also among high achieving pupils (Loh et al., 2014; Rahayu et al., 2011; Rahayu et al., 2011).

Experiments in teaching about batteries at the elementary schools, conducted in China, weren't successful (Lee, 2007; Lee & Chang, 2001). These experiments show that elementary knowledge about atoms and ions and some knowledge in chemistry are crucial for the understanding of the battery, and suggested that teaching about the battery should be postponed to the intermediate school.

4. The Research

4.1 Educational Background of the Research

Our research is based on the STSE (Aikenhead, 2003; Pedretii et al., 2004) and SSI (Tobin et al., 2011) curricular ideas containing physics, chemistry technological applications and concerns for the society and environment, together with constructivist approach to the teaching of science (Driver & Oldham, 1986), and is inspired by the study of Niaz and Chacón's (2003). The research was based on: (1) investigating students' previous ideas about electrolysis; (2) Exposing these ideas through experiences and class discussion; and (3) making an attempt to change misconceptions by performing hands on experiences and carrying out discussions taken form SSI ideas (Tobin et al., 2011). During the instruction, we also emphasized the role of the reduction potential regarding the battery and its connection to the activity hierarchy of metals and non-metals. Although one might expect the pervasive use of electrical technologies in modern civilization to support student learning and understanding of electricity, in the past that has not been the case. We suggest that enhancing the role of the battery within the teaching of electrolysis will lead to the idea that the electricity is separated into two kinds within the battery: electrons injected to the conducting wires and ions that go into the solution. These electrical particles move in the solution and convey matter from one electrode to the other (Faraday, 1834). Differentions move in different directions due to the different reduction potentials of the electrodes; these kinds of electricity will be defined as positive and negative.

4.2 Population, Sample and Previous Learning

The research was conducted among 45 college students, within their chemistry course.

4.3 Set of Experiences

General chemistry

1) The structure of the atom and its components. Atomic number and mass.

2) Chemical formula; reactions and formula.

3) Periodic table of elements: metals and non-metals.

4) Ions, ionic compounds, cations and anions, ion's charges.

5) The mole, chemical equations and their balancing, moles and masses.

6) Gas properties, molecular kinetics.

7) Chemical equilibrium, the effects of temperature pressure and concentrations on the equilibrium constant.

8) Oxidation and reduction, potential of reduction.

4.4 Experiences with Electrolysis

The electrolysis course contained the following set of experiences, which created the base for the learning of electrolysis. The experiences were carried out during 15 meetings (90 minutes each). Some of the experiences took longer than one meeting, and others needed a long discussion. In order to make the principles we wished to emphasize more transparent, most of the experiences were initially done in an electrolysis cell of one container with two electrodes inserted in it. These activities are related to the difficulties and misconceptions found in previous research.

4.4.1 Set of Experiences (Note 1)

1) (E1) Redefinition of the concepts: electric circuit, conductors and non-conductors, solution. Pointing at the existence of ions in some solutions and defining them as conductors. This experience is aimed to point at the way the electric current is transported through the electrolysis cell and through the solution in the battery.

2) (E2) Defining and expanding the ideas of conduction. In metal wires, current is carried by electrons, and the conduction in solution is carried by two kinds of ions moving in opposite directions to each other. When the bridge is introduced, it is emphasized that the current in the bridge is also made out of two-directional moving ions (Garnett & Treagust, 1992).

3) (E3) Electrolysis of water. Definition of the elements oxygen and hydrogen. Within this experience, the connection between chemistry and electricity is initiated, since the electric current is used to separate the elements of the water. The conclusion from the ratio of the volumes is that the number of Hydrogen particles doubles this of the Oxygen, confirming the equation of the water as H_2O.

4) (E4) Making the ideas of the former lesson (E3) significant, by a revision of Avogadro's law for ideal gases that follow the gas laws (in equal volumes of gases under the same temperature and pressure conditions there are equal numbers of molecules). The revision includes extending this law to include dilute aqueous solutions, and refining it to electrolyte solutions when some molecules split to form ions, thus enabling the transition of electrical current through the solution when electricity is exerted.

5) (E5) Presentation of Faraday's laws, following Niazand Chacón's ideas (2003):

A. The amount of materials accumulated on the electrodes are proportional to the quantity of electricity used, i.e., to the multiplication of the current by the time ($Q = i \times t$). This law connects the intensity of the current with the chemical reaction that takes place in the electrolytic cell. When experiencing Faraday's first law, the compounds that accumulate near the electrodes are identified by indicators and discussed. Masses that are amounts of matter are related to electric current, which hints to electric forces that exist in the particles of the materials.

B. The quantities of the materials extracted are reciprocity proportional to the valences. In a set of electrolysis cells in series, where the current is the same, the quantities of materials are proportional to the specific mass of the materials divided by their valances. Electricity is thus connected to the chemical concept of valence. When the valence is doubled, the amount of electricity needed for reduction is also doubled.

6) (E6) Identifying materials that were accumulated on, or near, the electrodes by the use of indicators. This experience is aimed at exemplifying various kinds of electrolysis processes and discussing them.

7) (E7) Coating by electrolysis. The experiment is done in three stages:

A. Before using the coating by electrolysis, an iron nail is inserted into a copper compound solution and is coated by copper. This experiment helps to establish the activity hierarchy of the metals.

B. copper from a copper compound solution coats the negative electrode (Cathode) in the electrolytic cell.

C. Activating an advanced method of coating to emphasize the technological aspect.

8) (E8) Electrolysis of NaOH (Sodium Hydroxide). While cooking, oil is added to the NaOH solution, on one electrode Hydrogen is extracted, it combines with the oil and creates margarine, on the other side we get soap made out of sodium base (NaOH) and oil. Both compounds are extracted and identified. This experiment can be used to demonstrate how both margarine and soap compounds are made, thus bridging the disciplines of electrolysis, nutrition and health.

9) (E9) Cleaning impure water by electrolysis and evaporation. This experience is aimed at demonstrating some technological and practical uses of electrolysis, and their connection to environmental improvement and the effect on society (SSI). The importance of these experiences is discussed in the classroom.

10) (E10) Creating an electric cell from lemon and two electrodes made out of two different metals, as a version of the original electric cell of Volta. This cell is discussed and the positive electrode (Anode) and negative electrode (Cathode) are explained and defined (Garnett & Treagust, 1992, A, D, E).

11) (E11) the electrodes of a simple electrolysis cell are defined (Garnett & Treagust, 1992). During the discussion, it is stressed that the positive and negative signs of the electrodes are defined by the charged points of the source they are connected to. After the discussion, the pupils are asked to draw a diagram of an electrolysis cell, and identify the signs of the electrodes and the other components of the cell (similar to Figure 3).

12) (E12) Creating an electrolysis cell that contains two electrodes, salt bridge, voltmeter and solutions. Near the anode we inserted three kinds of water in three separate experiments: distillated water (which

does not conduct electricity), Dead Sea water (containing a high concentration of salt), and faucet water (containing a small amount of salt and conducts electricity). Copper compound was inserted near the cathode. At this point, the fact that a DC power is needed for electrolysis is emphasized, and the role of the salt bridge is explained. It is emphasized that the current in the salt bridge is not made out of electrons, but rather made of ions. Inserting a metal conductor stops the current, and the cell does not function.

13) (E13) the hierarchical set of the activity of the conductors: metals and graphite are introduced, and the potential reduction of the electrodes is discussed together with the function of the battery and its voltage. Pupils are asked how do the signs of the battery defined and how do they influence the signs in the electrolysis cell.

5. Results

The research was conducted through the following three stages: survey of previous ideas and a pre-test (Table 1), instruction, and a post-test (Table 1). The results of high school and college are compared in both Tables. The same test was used during the pre-test and post-test stages (for test see appendix).

Table 1. General Results of the Electrolysis Test

Question number	Pre-test correct answers		Pre-test wrong answers		Post-test correct answers		Post-test wrong answers	
	High-School n=25	Collage n=45	High-School n=25	Collage n=45	High-School n=25	Collage n=45	High-School n=25	Collage n=45
1	20	56	80	44.	40	89	60	11
2	32	40	68	60	40	87	60	13
3	16	30	84	69	32	73	68	27
4	12	24	88	76	64	96	36	4
5	72	67	28	33	76	98	24	2
6	20	44	80	56	72	84	28	26
7	8	9	92	91	0	24	100	76
8	0	2	100	98	72	82	28	18
9	8	22	92	78	88	78	12	22
Mean	20.8	32.9	79.8	67.1	53.6	70.1	46.8	29.9

No. of east Jerusalem, high school pupils is 25. Number of college students is 45.

The results are given in percentages.

There was a significant development in the percentage of correct answers given by the college students' between the pre-test and the post-test stages ($p<0.05$). There is a significant difference between the averages of correct and wrong answers of the college students at the post-test level. A significant difference was not observed at the high school.

Table 2. Pre-Test and Post-Tests Results

Question	Option	Pre-test answers		Post-test answers	
		High-School %	Collage %	High-School %	Collage %
1	A	40	22	20	2
	B	28	16	28	7
	C	12	6	20	2
	D (Correct)	20	56	32	89
2	A	16	9	20	2
	B	12	7	20	2
	C (Correct)	32	40	40	87
	D	40	44	20	9
3	A	20	13	0	0
	B	24	16	0	0
	C	40	40	68	27
	D (Correct)	16	31	32	73
4	A (Correct)	12	24	64	96
	B	40	32	0	0
	C	24	22	24	4
	D	24	22	12	4
5	A	20	7	0	0
	B	0	0	0	0
	C	8	26	24	2
	D (Correct)	72	67	76	98
6	A(Correct)	20	45	76	84
	B	60	33	20	11
	C	8	18	4	5
	D	12	4	0	0
7	A	40	60	16	12
	B	28	24	0	0
	C	8	7	84	64
	D (Correct)	24	9	0	24
8	A	80	80	28	18
	B (Correct)	0	2	72	82

	C	8	7	0	0
	D	12	11	0	0
9	A	0	0	0	0
	B	80	62	12	22
	C (Correct)	8	22	88	78
	D	12	16	0	0

The No. of pupils in collage is 45.

The No. of pupils in High-school is 25.

The distribution of each answer among the destructors in bot 5h groups.

The results are given in percentages.

6. Discussion

Most of the percentages of correct answers of the college students at the pre-test and at the post-test stages were higher than those of the high school pupils. These results are due to better preparation in chemistry. For example, the detailed curriculum in college chemistry includes atomic physics that enabled a more modern definition of the ion. College student game more attention to the identification of the signs of the electrodes of the electrolysis cell (the sign depends on the source), and battery (the sign depends on the relative activity of the two rods). Furthermore, college chemistry gave increased emphasis to the importance of the relative definition of the half-cell, and the definitions of the currents in metals and solutions.

In the instruction, attention was given to the chemical properties of the elements of the electrodes. Q2 results improved considerably from those of the high school and previous research, as the relative property of the reduction potential was discussed thoroughly in the general chemistry course, and repeated during the special instruction of the electrolysis. Q3 deals with the current in the cell, which was notified as difficult both in previous research and at the high school. The results (Tables 1, 2) improved from pre to post stages, and they are quite acceptable in the college's post-test (Tables 1, 2). This problem (Q3) was discussed in the college, stressing that the electrodes' sings in the electrolysis cell, are similar to those of the source. In Q4 the participants at the post stage stated that the current in the wires is carried by electrons. This problem caused much difficulty to the high school pupils. At the same time, the results of Q5 stressed the fact that in the solution, and also at the bridge, current flow is due to ions results improved from pre to post stage. Q6 deals with products, and the results were quite acceptable in both populations. Carrying many experiences regarding products extracted near the electrodes of the electrolysis cell, caused the knowledge accumulation, and was expressed in the results of the post-tests at both groups. Q8 repeats the problems of Q4, Q5 and Q6, where the pupils have to deny the possibility of electrons moving in the bridge (electrons moves only in the wires), and prefer Chlorine to Potassium, since Chlorine is included in the cell compound. Q9 was generally answered correctly.

The main problem of the test is Q7, which was the only problem in this research where wrong answers exceed the correct ones (significantly). The relative successes of the college pupils in the post involvement stage shows that the low percentages of correct answers regarding this problem, initiated from the fact that the participants are not experienced with the formal logic of assertion, reason and result, and the relevance of this logic to the special problem of the kind of current that moves in the bridge.

7. A Comparison between High School and College

The average achievements of the college students were higher than those of the high school pupils in all but one question (Q9). These results are not surprising since we would expect that college students would do better than high school pupils. Improved achievements of the college students may be due to a better preparation in chemistry, more emphasis on the signs of the electrodes and distinguishing the current in the wires from the current in the solution. The discussion of the results of the high school pupils was based on the work of Ogude and Bradley (1996), who described sources of miss-conceptions (in brackets are the numbers of questions related to these difficulties in problems Q1 to Q9):

(a) Identifying the anode and cathode in battery cell (Q1).
(b) The need for a standard half-cell (Q2).
(c) Current in a battery cell (Q3, Q4).
(d) The charge of the anode and cathode in the battery cells and their relations to the reduction potentials (Q1, Q8).
(e) Identifying the anode and cathode in electrolytic cells (Q4).
(f) Predicting the products of electrolysis and the magnitude of the applied EMF between the electrodes (Q6, Q8, and Q9).
(g) The current in the salt bridge: (Q7).

All the above difficulties were found among high school pupils, except the sixth one (f), which was dealt with in many experiences. Observing the results among the college students, a major improvement was found regarding all these schemes. We attribute the improved results partly to a better base in general chemistry. Acceptable percentages of correct answers (of the order of magnitude of 40%-56%) in domains that relate to chemistry, was found even at the college pre-stage, and was enhanced at the post stage.

Much attention was given to identifying the electrodes of the galvanic and the electrolysis cells, relating the sings of the electrodes of the electrolysis cell to the source, and those of the galvanic cell to the reduction potentials of the electrodes. The potentials of the half-cells were related to hydrogen (reduction potential zero). Discussions were carried out in order to explain that current in the wires is made of electrons, but electrons are not accepted to the solutions of the cells and bridge. In the solution, current is carried by positive and negative ions moving in opposite direction. Significant improvement was found between high school and college.

This research cannot be defined as a controlled experiment since the groups differ in background and maybe in cognitive ability. All we may say is that difficulties confronted in the high school experiment and other former research affected the instruction at the college experiment, and resulted with good achievements there. Attitudes at the college were evaluated by individual oral discussions with the college participants. These discussions showed that the students were satisfied with the guidance they received and said it helped them to identify and use the concepts better.

More work is needed at the high school as well as in the college to support our conclusions.

8. The Place of the History of Science in Science Education

The research described in this paper was influenced by the history of science, and especially by the history of electricity. Many of the experiences described above are inspired by famous occurrences and anecdotes in the history of science, and the sequence of experiences was inspired by the sequence of historical events.

As a general idea, the development of science is suggested here to be understood as made of arguments and controversy, when this notion has pedagogic merit. The scientific development, as we see it, is composed of sets of breakthroughs, followed by interpretations of the meaning of the observed events. Different researchers who observed the same events, gave them different interpretations; the more fruitful ones among them were preferred by later development. The explanations given by the different researchers were accompanied by new experiments that supported the new insights of the arguing scientists. These explanations and experiences should be incorporated into the syllabus, and will prove to be fruitful.

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Note

Note 1. This set of experience also used in Bar et al. (2016).

Appendix-Test

1. In a battery cell constructed by Ni and Ag electrodes, the Ni electrode is the anode and the Ag electrode is the cathode. Which one of the following statements is TRUE about the charge of the electrodes of this cell?

a) The Ni electrode is negatively charged because it releases positive ions.

b) The positive sign of the Ag electrode indicates that Ag has higher reduction potential.

c) The Ag electrode is negatively charged because it attracts electrons.

d) The Ni electrode is positively charged because it attract ions.

2. Which one of the following statements is CORRECT about the standard reduction potential?

a) Standard reduction potentials can be measured independently without the use of other half-cell reaction.

b) Half-cell reactions are spontaneous.

c) All standard reduction potentials are measured relative to standard reduction is relative to the standard hydrogen electrode.

d) The metal which has the most positive standard reduction potential is the most reactive.

3. In an electrochemical cell (electrolysis cell), conduction through the electrolyte is due to:

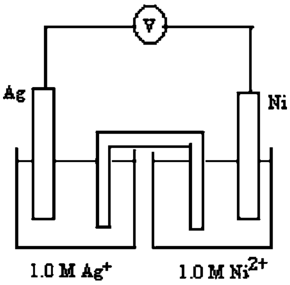
a) Electrons moving through the solution attached to the ions.

b) Movement of negative ions.

c) Electrons moving through the solution from one electrode to the other.

d) Movement of both positive and negative ions.

4.



Ag (aq) + e, Ag(s), Eo = + 0.80 V

Ni_2 (aq) + 2e, Ni(s), Eo¼=+ .024V

In the electrochemical cell drawn above, electrons from the cell flow through the: toward the:

a) Wire, silver electrode.

b) Wire, nickel electrode.

c) Wire, silver electrode and salt bridge, nickel electrode.

d) Wire, nickel electrode and salt bridge, silver electrode.

5. The function of a salt bridge in an electrochemical cell is to:

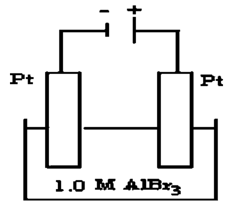
a) Form complex ions with the oxidation products.

b) Permit electrons to flow through the solution.

c) Keep the levels of liquids equal in both half-cells.

d) Allow positive and negative ions to enter and leave both half-cells.

6.



What are the products at the anode and at the cathode in the above electrolytic cell? Al$_3$+, H_2O, Br_2, and O_2 are arranged in the order of increasing standard reduction potentials in the following way Al$_3$þ\H$_2$O\Br$_2$\O$_2$

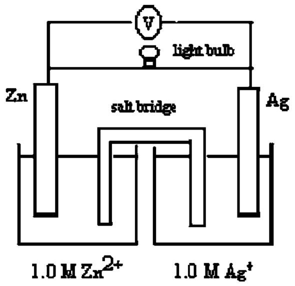
a) The anode is HBr and the cathode is Al_2O_3.

b) The anode is Br_2 and the cathode is H_2.

c) The anode is Br_2 and the cathode is Al.

d) The anode is O_2 and the cathode is Al.

7.



Evaluate the following assertion and reason listed below:

- Assertion-If the salt bridge in the picture above was replaced by a copper wire (an electrical conductor), the light bulb would be lit.
- Reason-There will be a continuous flow of electrons in the electrolyte solutions that can pass through the copper bridge.

a) Both the assertion and the reason are correct.

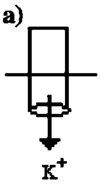
b) The assertion is correct, but the reason is incorrect.

c) The assertion is incorrect, but the reason is correct.

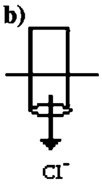
d) Both the assertion and the reason are incorrect.

8. Which drawing best describes the current flow occurring at the salt bridge in the PbCl$_2$ solution?

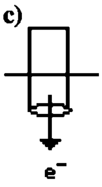
a)



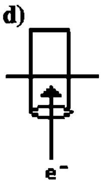
b)



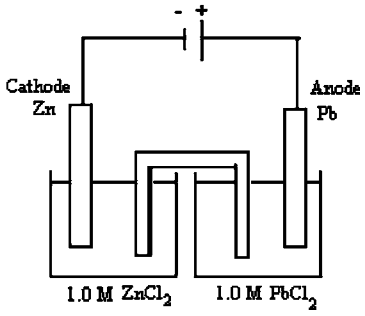
c)



d)



9.



Pb^{2+}(aq) + 2e,Pb, Eo = -0.12 V

Zn^{2+}(aq) + 2e,Zn, Eo = -0.76 V

What is the cell potential for the above electrolytic cell?

a) +0.88 V

b) –0.88V

c) +0.64 V

d) –0.64 V