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The Effectiveness of Teachers' Use of Demonstrations for Enhancing Students' Understanding of and Attitudes to Learning the Oxidation-Reduction Concept

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ABSTRACT

In this study we explored whether the use of teachers' demonstrations significantly improves students' understanding of redox reactions compared with control group counterparts who were not exposed to the demonstrations. The sample consisted of 131 Israeli 8th graders in middle schools (junior high school). Students' attitudes and achievements as well as their understanding of redox and electrolysis were assessed by administering a questionnaire that investigated their attitudes (perceptions) towards a demonstration in chemistry. The findings showed that the experimental group's achievements and understanding of the subject were statistically significantly better than those of their control group counterparts.

Keywords: chemistry demonstrations, redox reactions, electrolysis, achievement, attitudes, electrochemical row, chemistry education

INTRODUCTION

Rationale for the Study

The concept of oxidation-reduction is one of the key concepts taught and learned in chemistry in the middle school (junior high schools) in most countries around the world (GCE Ordinary Level). Butts and Smith (1987), for example, reported that high-school students found the concepts of electrolysis relatively difficult to understand. In another study of 11th grade

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State of the literature

- Most of the studies on demonstrations are general, namely, comparing students using experimentations with teachers' demonstrations, covering a wide range of topics and concepts, less of these studies discuss the effectiveness of demonstrations.
- Few studies highlight that good demonstrations can enhance students' understanding, motivation, and attitudes.
- Demonstration in chemistry may be defined as a pedagogical event whose objective is to illustrate a scientific concept.
- The literature state that high percent of the students considered oxidation-reduction and electrolysis is one of the most difficult concepts.

Contribution of this paper to the literature

- This study concentrates on demonstration's effect on students' achievements and attitudes in a special sector "the Arab sector in Israel".
- Increasing the spectrum of studies on demonstrations in the redox and electrolysis reactions in which support the literature that well planned properly demonstrations lead to improvement in the achievements and efficiency students.
- Based on students' interview results, demonstration affected them very positively, brought these redox concepts closer to their hearts, increased the extent of interest and attractiveness, and increase their level of motivation and satisfaction. Hence, it can serve as an effective platform for enhancing students' understanding of certain chemistry concepts.

students conducted in Nigeria, Okpala and Onocha (1988) found that fifty percent of the students considered electrolysis one of the most difficult concepts. In a report by the Cambridge University Local Examination Union concerning the achievements of students from Singapore in GCE O Level chemistry exams, it was noted that concepts related to electrochemistry and electron transfer are associated with severe learning difficulties and with misconceptions (Tan, 2000).

As mentioned before, oxidation-reduction is one of the most important concepts within the topic of chemical reactions taught in middle school. Gillespie (1997) stated that chemical reactions (including redox reactions) are one of the six key concepts in chemistry. Based on this premise, it was decided to investigate the learning and understanding of the concept by using classroom demonstrations. In this study we created a pedagogical intervention in order to help students better understand the concepts of oxidation-reduction and electrolysis, which are considered as difficult concepts in chemistry. The main goal of the current study was to investigate the educational effectiveness of using demonstrations in the context of teaching and learning the concept of oxidation-reduction in secondary school chemistry.

More specifically, the main objectives of the current study are as follows:

- To explore the effectiveness of demonstrations regarding students' understanding of the oxidation reduction concept;
- To explore whether demonstrations improve students' attitudes toward chemistry and increase their motivation to learn science.

THEORETICAL BACKGROUND

The issue of using demonstrations (to be defined later) in a chemistry classroom has often been discussed in the research literature (Hofstein & Lunetta, 1984; Bare, & Andrews, 1999; Thompson & Soyibo, 2002). Among the questions posed in the literature, we found the following: Are demonstrations as effective as individual students' experimentations? Do demonstrations promote the understanding and internalization of scientific concepts? Can demonstrations develop students' thinking skills? And what conditions are needed to make teachers' demonstrations more effective than individual students' experimentations? Although lecture demonstrations have been conducted in chemistry classrooms for a long time, little research exists that documents the frequency that such demonstrations are employed or their effect on learners' motivation and performance (Price & Brooks, 2012; Odom & Bell, 2015). Shakhshiri (1992) remarked that "Educators have often searched for various ways to teach science". The use of demonstrations is one of numerous pedagogical interventions that have been adopted for enhancing students' interest. Experiments and demonstrations that confirm a physicochemical phenomenon such as illustrating chemical processes by light-sticks (Kuntzleman, Rohrer & Schultz, 2012) can be used to facilitate understanding certain chemical concepts, for example, acid-base reactions, redox reactions, fluorescence, quantum chemistry, and thermodynamics.

A demonstration involves illustrating a point in a lecture or a lesson by means of something other than routine visual aids or other means of instruction. A demonstration in chemistry may be defined as a pedagogical event whose objective is to illustrate a scientific concept (Taylor, 1988). This definition can be broadened and divided into three categories: (1) Visual aids used in an unusual manner, for example, teachers and students using body movements to illustrate acid/base chemistry and oxidation/reduction; another example would be Lomax's (1994) kinetic class, in which movement is used to reinforce the concept of chemical transformations. (2) Analogical demonstrations, in which one uses a phenomenon whose behavior is similar in relevant aspects to that of the scientific concept under discussion. A good example of this would be the use of steel balls on the glass cover of a watch to illustrate the density of atoms in a pseudo-metallic structure. (3) Real experiments, which are the most common type of demonstration: Shakhshiri presents numerous examples in his five published books (1983, 1985, 1989, 1992 & 2011). According to Chiappetta and Koballa (2002) and Shakhshiri (1992), well prepared and properly presented demonstrations have the potential to enhance students' understanding of chemistry concepts. Similarly, Hofstein and Lunetta (1982, 2004), in their comprehensive reviews, came to the conclusion that demonstrations have the potential to enhance learning, motivation, and attitudes.

Gardner (1978) suggested that demonstrations may enable learners to evoke the “wow” experience. This consequently can increase their curiosity and enhance their reasoning abilities. In addition, it may have an impact on students’ achievements (Gerber, Cavallo & Marek, 2001). Moreover, there are occasions in which teachers’ demonstrations are educationally more effective than are students’ own experimentations (Hofstein & Lunetta, 2004, Lunetta, Hofstein & Clough, 2007). Although research on the effectiveness of demonstrations has been conducted since the early 1960s, most of the studies were general, namely, comparing students using experimentations with teachers’ demonstrations, covering a wide range of topics and concepts. A number of research papers reported clear benefits when demonstrations are used for teaching the sciences. In a study on college introductory physics courses, Buncick, Betts, and Horgan (2001) found that demonstrations encourage generalization because they promote active participation on the part of the students. An elevated level of student attention and involvement in tasks has also been reported for demonstrations carried out in high-school chemistry courses. For example, Meyar et al. (2003) have shown that demonstrations encourage student involvement, since they are less teacher-oriented and give students an opportunity to produce questions and to become more active in the learning process. This in turn can motivate students to undertake an initial inquiry and also provides a learning opportunity, because it helps create mental links between new and previous learning. In addition, Meyar et al. reported that students can illustrate cognitive strategies by observing the teacher as he thinks out loud while doing the demonstration and as he formulates questions that lead to an explanation of the concepts in question. This may challenge students’ preexisting understanding and can encourage perceptual understanding.

The traditional teaching strategy of using a lecture-type approach may perhaps be favored by those students who are in favor of the didactic methods of learning and who are considered conscientious (Hofstein & Kempa, 1985; Kempa & Diaz, 1995). Demonstrations in use as a teaching strategy may prove beneficial for students with different or special learning needs. It is assumed that, when combined with traditional methods, demonstrations can be effective for low-achieving students with high visual and spatial intelligence but with limited cognitive abilities (Meyer et al, 2003; Rade, 2009; Baddock & Bucat, 2008). Although considerable research has been conducted on the use of demonstrations to teach chemistry, few studies have focused on how effective this method is in promoting cognitive involvement. Hofstein et al. (2005) and Dkeidek, Mamlok-Naaman, and Hofstein (2012) published a study on question asking as a tool for developing high-order thinking skills in the chemistry laboratory. They showed that students in the Jewish sector in Israel ask more questions than their Arab counterparts. This may result from a lack of knowledge in this area, which in turn, may be one of the reasons why it has been so difficult to justify the allocation of teacher time and resources for demonstrations. Furthermore, the use of demonstrations as a teaching/learning technique has not been sufficiently studied in terms of how well it promotes, challenges, and helps develop children’s conceptual understanding.

In addition, demonstrations could be conducted by the chemistry teachers as a method of triggering a discussion between groups of students, which can be termed cooperative learning. This approach is an educational learning technique whereby students collaborate in small groups on a certain task, project, or argumentation. Towns & Grant (1997) noted that in order to develop significant learning, students must process information actively. Cooperative learning activities can create an environment in which students actively pursue their tasks by sharing insights, ideas and representations, providing feedback, and by teaching each other. The latter is also very consistent with studies that show that demonstrations in science encourage generalization because they promote active involvement by students and also enhance students' attention level. It may also be beneficial to include elements of cooperative learning in demonstration lessons, in order to improve students' understanding of what is taught (Eilks, Prins & Lazarowitz, 2013).

Research questions

The purpose of this study is to examine how teaching and learning chemistry using demonstrations influences students' understanding of the topic of oxidation-reduction and its related concepts. More specifically, the two research questions of interest are as follows:

1. Are there significant differences in students' perceptions of the efficiency and importance of demonstrations between those students who experienced demonstrations in the teaching of oxidation-reduction and those who did not?
2. Are there significant differences in students' achievements between students who learned with and those who learned without demonstrations?

METHODS AND RESEARCH SAMPLE

The nature of demonstrations that were developed and implemented in the experimental class

A series of demonstrations were used to illustrate the concepts of oxidation-reduction and electrolysis to be taught. The following demonstrations were chosen:

- Opening demonstration: Steel wool in a copper sulfate solution and copper in a silver nitrate solution.
- Various metals in a solution of other metallic ions in order to demonstrate and discuss the electrochemical row.
- Electrolysis of a copper chloride solution.
- Electrolysis of water – by using Hoffman's apparatus

The student sample

The participants in this study consisted of two groups: an experimental ($N=64$) and a control ($N=67$) group, each consisting of two classes. All four classes (8th grade) were from the same high school in an Arab educational sector located in the northern part of Israel. Both

groups had similar achievement scores and both had a heterogeneous distribution of achievement levels according to a mapping test in chemistry (see **Table 2**).

The experimental group studied oxidation-reduction using the traditional method according to the Israeli curriculum in which a long teaching and learning sequence and relevant demonstrations were introduced by the teachers. The control group studied oxidation-reduction the same way, but with no demonstrations. Both groups were taught by an experienced chemistry teacher.

Research Instruments

The attitude questionnaire: The student perception of a chemistry questionnaire consisted of 10 items formulated using a five-point Likert-type scale where 1 = strongly agree and 5 = strongly disagree (see appendix 1). The questionnaire was adapted from that of Majerich & Schmucklet (2007) and modified for the present study (Cronbach's α 0.78).

Multiple-choice test: The test consisted of a preliminary array of 15 multiple-choice questions on the topics of oxidation-reduction and electrolysis, each with four possibilities (answers). The questions were taken from a variety of different sources (chemistry textbooks, chemistry exercise books, and test questions from previous years) and adapted to their present purpose. The test was content validated by two experts with a chemistry and science education background. Both experts suggested changes in the formulation and requested replacing three questions in order to have a variety of questions at different levels according to Bloom's taxonomy. Esiobu and Soyibo (1995) argue that for test items to effectively assess students' comprehension of scientific concepts they must go beyond the comprehension level in Bloom's taxonomy.

Here is a sample question from the test:

What happens when water undergoes electrolysis?

- Negative hydrogen is attracted to the anode and negative oxygen is attracted to the cathode and both become neutral elements.
- Positive hydrogen is attracted to the anode and negative oxygen is attracted to the cathode and both become neutral elements.
- Hydrogen gas is produced on the cathode and oxygen is produced on the anode and the ratio of hydrogen: oxygen is 2:1.
- Hydrogen gas is produced on the anode and oxygen is produced on the cathode and the ratio of hydrogen: oxygen is 1:2.

Oral interviews: In addition to the quantitative data generated through the achievement test and the attitude questionnaires, a structured interview was conducted with a sample of students from the experimental group. The interview was semi-structured in which all those who were interviewed were asked the same questions. The interview focused on the following

aspects: students' understanding of the related subject matter, their satisfaction, their attitude towards learning chemistry, their interest in science, and motivation.

Research procedure: **Figure 1** is a schematic outline illustrating the various activities and assessment procedures used in the two groups.

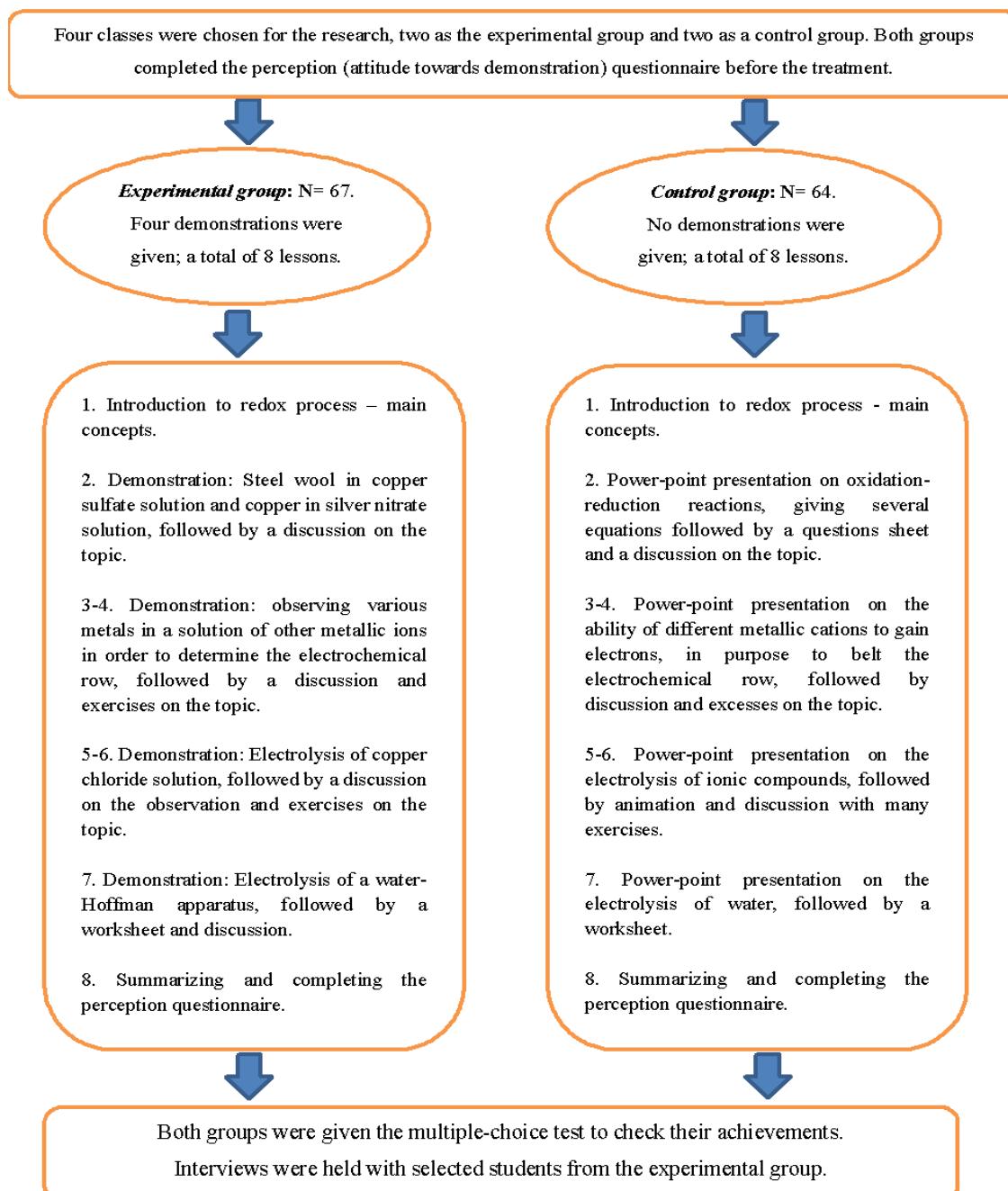


Figure 1. A schematic presentation of the research study: A time line scheme

In both groups an opportunity was given for establishing a dialogue and for asking questions during the lessons, but we found that in the experimental group the dialogue was more dynamic and more questions were asked. Moreover, in the experimental group more active student-teacher interactions during the demonstration lessons were detected than in the traditional lessons. It is important to note that in the control group, in both classes, pupils expressed a desire to present their experiments related to or based on the idea of electrochemical row electrolysis in ionic solutions. The demonstration's efficiency and the importance of the variable were calculated as the mean of students' answers in the questionnaire by testing for students' perceptions of the demonstration's efficiency and importance. Each student received a grade between one and five, with a higher grade indicating that the student perceived the demonstrations as being more efficient and important for learning. The comprehension and achievement variable was measured by the students' grades on the test.

FINDINGS

Table 1 presents the means and the related standard deviations for students' perceptions regarding the chemistry demonstrations (their effectiveness and importance). **Table 2** presents means and standard deviations for students' achievements in the test administered to them before the treatment (a diagnostic test), as well as to ensure that both groups had a similar starting point with respect to their achievements.

Table 1 shows that regarding students' chemistry achievement no significant differences were revealed. In other words, both groups had a similar initial achievement level.

Table 1. Means, standard deviations, and t-value for student achievement in the pre-treatment test

Group	N	M	SD	t	p
With demonstrations	67	80.62	7.57	0.56	N.S.
Without demonstrations	64	81.84	9.81		

Table 2. Comparison of means and standard deviations (and t value) related to students' perceptions (attitude) regarding the value of demonstrations

Groups	N	M	SD	t	p
With demonstrations	67	2.11	0.34	0.17	0.86
Without demonstrations	64	2.12	0.28		

Results related to the 1st question

The differences between the two groups following the treatment (exposure to demonstrations in the experimental group) were determined by a series of t-tests for the two research (independent) samples. **Table 3** shows means, standard deviations, and the t-test value for the demonstration's efficiency and for the importance of perception between both groups (the group of students who had been exposed to the use of demonstrations in the teaching of the redox and electrolysis process and the group who had not been exposed to the demonstrations). **Table 4** shows the means and standard deviations for students' efficiency in the test administered to them after the experiment, and the value of the t-test.

A significant improvement occurred in the perceptions of those students who had been exposed to demonstrations when learning redox and electrolysis.

Table 3. Means and standard deviations for the demonstrations' effectiveness and importance for comparing the two groups, and the value of the t-test

Group	N	M	SD	t	p
With demonstrations	67	3.67	0.30	20.06	0.0001
Without demonstrations	64	2.24	0.28		

Table 4. Means and standard deviations for students' perceptions in the experiment group before and after the treatment

Group	N	M	SD	t	p
Before	67	2.11	0.34	20.25	0.000
After	67	3.67	0.30		

Table 5. Means and standard deviations for the two groups' achievements after the treatment, and the t-test value

Group	N	M	SD	t	p
With demonstrations	67	86.79	6.03	3.26	0.002
Without demonstrations	64	81.03	8.16		

Table 6. Means and standard deviations for achievements of students in the experimental group before and after the treatment, and the value of the t-test

Group	N	M	SD	t	p
Before	67	80.62	7.57	3.72	0.002
After	67	86.79	6.03		

Results related to the 2nd question

The mean achievements among those students who had been exposed to demonstrations after the treatment (exposure) was 86.79, whereas among those not exposed the mean was 81.03. The t-test showed a significant difference between the means ($t = 3.26$, $p < 0.01$).

A significant difference was found between the two cases ($t = 3.72$, $p < 0.001$), showing that a significant improvement had occurred in the achievements of those students who had been exposed to demonstrations when learning redox and electrolysis. These results confirmed our second hypothesis.

Interviews held with the students in the experimental group

In order to determine the general attitudes (and students' interest in addition to the quantitative data assembled via the questionnaires, a structured interview was conducted with a small number of the experimental group's students. The answers for each question follow:

1st question: How did the demonstration method affect your understanding and your satisfaction related to the oxidation - reduction and electrolysis subjects?

Answers:

- *I liked it, because these scientific experiments are relevant to our daily life.*
- *Redox and electrolysis themes help us gain a better understanding of life and events.*
- *It had a positive impact on understanding electrolysis and redox.*
- *After experiencing the demonstration method, I had a better understanding of the issues related to redox and electrolysis.*

2nd question: If you choose to be a science teacher in the future, what method would you choose to implement in the science class and why?

Answers:

- *The delivery method using a computer and the method of combining the laboratory with demonstrations.*

- *The demonstration method, because of its positive impact on students.*
- *Providing examples of things that occur in everyday life to help students understand them more.*
- *The demonstration method in the laboratory, to make students take redox and electrolysis more seriously and to understand the importance of these topics.*

3rd question: How did this method affect teaching the application of science in everyday life?

Answers:

- *Students like to try things; they are curious about many things.*
- *It increases the students' desire to apply things in everyday life.*
- *It exposes the student to a variety of issues and how to use science, including its dangers and its positive effects.*
- *It had a positive effect, leading to better understanding of what is happening around us in everyday life.*

4th question: How and to what extent has this method influenced your interest in the sciences - What is your feeling?

Answers:

- *It influenced me greatly; I'm now more interested in learning science.*
- *The science professionals affected me very much; I love it much more now.*
- *My interest grew more than in the past; I feel proud to have achieved this level.*
- *This teaching method increased my desire to study science; I feel more comfortable because I understood it more.*

5th question: Has your perception of the sciences changed? How?

Answers:

- *No serious difficulties; I still believe that the science profession is interesting and beautiful.*
- *Yes, my anxiety disappeared towards the science profession; learning it became easier and more interesting.*
- *Yes, I like science more and I now really want to study it.*
- *No, since I already had a positive perception toward science, especially chemistry before we saw the demonstrations.*

6th question: How did this method affect your motivation to continue studying science in the future? To what extent?

Answers:

- *The teacher who used this method really affected me.*
- *I will continue to learn; maybe I'll be a teacher.*

- *A positive effect regarding the desire to learn and teach science in the future.*
- *A very positive effect regarding my motivation leading to more satisfaction in studying science.*

Based on the students' responses in this interview, it can be concluded that teaching electrolysis and oxidation-reduction via the demonstration method affected them very positively, brought these subjects closer to their hearts, made studying them easier, increased the extent of interest and attractiveness, and elevated the students' level of motivation and satisfaction.

DISCUSSION

The above findings show that the use of demonstrations helps students to better understand the subject of redox reactions and electrolysis in chemistry. Exposure to demonstrations improves students' perceptions of their learning efficiency and the importance of the subject and also enhances the students' achievements and their understanding of redox concepts. This result is compatible with Sweeder and Jeffery's (2013) finding that demonstrations, if planned properly, and if they are effectively integrated into the learning of concepts, have potential to play an important role in students developing a deep and rich understanding of chemical concepts.

Demonstration sessions were found to promote thinking skills and to enable students to think more creatively. Based on their perception (attitude) questionnaire as well as the interviews, it is reasonable to assume that the sessions helped them understand the redox and electrolysis processes beyond what their textbook provided and enabled them to better assess and understand the uses of such processes in their everyday life. Importantly, the students expressed interest in learning more about redox and electrolysis processes.

The statistical analysis used in testing the first research hypothesis revealed that a significant difference exists between those students who had been exposed to demonstrations when studying concepts in science and those students who had not been exposed to them, with respect to their perception of the efficiency and importance of the use of demonstrations. The first hypothesis was therefore validated: exposure to demonstrations clearly improved students' perceptions of the efficiency and importance of demonstrations. Thompson and Soyibo (2002) reported that their experimental group's achievements were statistically significantly better than those of the control groups in understanding electrolysis processes. The statistical analysis that tested the second research hypothesis found a significant difference between students who had been exposed to demonstrations when studying concepts in science and those students who had not been exposed to demonstrations with respect to the comprehension of concepts; the second hypothesis was therefore validated. It is in line with the finding of Price and Brooks (2012) who claimed that demonstrations improve students' performance on practice assignments, laboratory investigations and exams, as well as enhance student's understanding of concepts.

It is clear that students prefer the demonstration sessions and accept their use in chemistry class. All the students who participated in the study, when asked whether they prefer studying by demonstrations or by the traditional method, replied that demonstrations were preferable. A number of students thought that in addition to demonstrations, lab sessions or manual activity sessions could be useful as follow-up activities after the demonstration sessions. At any rate, they agreed that even without manual activity sessions the demonstration lessons are superior to regular lessons.

Thus, we can conclude that demonstrations are useful for facilitating and developing learning, since they promote student interest in the lessons and provide teachers with a greater variety of pedagogical tools. Moreover, a statistically significant improvement was found in the achievements and efficiency of those students who were exposed to demonstrations in the redox and electrolysis reactions. We can explain that by the fact that demonstrations can make the lesson livelier and make teaching and learning of science more enjoyable and interesting, leading to better understanding. Therefore, we suggest extending this strategy to other subjects in chemistry as well as to other disciplines.

CONCLUSIONS AND IMPLICATIONS

The current study provided evidence that, if planned properly, demonstrations can serve as an effective platform for enhancing students' understanding of certain chemistry concepts as well as increase their motivation and interest to learn chemistry. This study focused on the topics of oxidation-reduction and electrolysis; more key concepts should be researched in order to obtain a more comprehensive picture regarding the implementation of educationally effective demonstrations. We operate in an era in which many attempts are made to develop pedagogical interventions with the goal in mind of enhancing students' interests in attitudes towards learning science in general, and chemistry in particular. In the current paper we attempted to enhance middle school students' conceptual understanding of the concept "oxidation reduction". It is recommended to develop additional similar demonstrations to support the learning of other key concepts taught in middle and high-school chemistry lessons.

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Appendix 1: Questionnaire for students' perception regarding the use of demonstrations in chemistry class

Statement No.	Statement	5 strongly agree	4	3	2	1 strongly disagree
1	It would be interesting to have a demonstration in every lesson.					
2	The science demonstrations helped me focus my attention on the chemistry topics in everyday life.					
3	Demonstrations in the classroom are superfluous because the textbooks contain all you need.					
4	I understand the material without demonstrations.					
5	The science demonstrations enhanced my learning of the chemistry course material.					
6	I find it difficult to comprehend the demonstrations.					
7	I prefer to learn through the demonstrations in chemistry class.					
8	Demonstrations make me tired and don't interest me.					
9	The science demonstrations arouse my curiosity, and motivate me to learn more chemistry.					
10	The science demonstrations make me think more about chemistry.					