The effect of Process Oriented Guided Inquiry Learning (POGIL) on 11th Graders' conceptual understanding of electrochemistry

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Abstract

The purpose of this study was to investigate the effect of Process Oriented Guided Inquiry Learning (POGIL) method compared to traditional teaching method on 11th grade students' conceptual understanding of electrochemistry concepts. Participants were 115 students from a public school in Turkey. Nonequivalent control group design was used. Two experimental groups and two control groups were randomly selected. The experimental groups were taught using the POGIL method, while control groups were taught using the traditional teaching method. An Electrochemistry Concept Test (ECT) was administered to both groups as a pre-test and post-test in order to assess the students' misconceptions and their conceptual understanding of electrochemistry concepts. Gain scores were compared using independent-samples t-test. The results showed that the POGIL method resulted in a better acquisition of scientific conceptions and in changing misconceptions in electrochemistry concepts than with traditional teaching methods.

Keywords: conceptual understanding, electrochemistry, alternative conceptions, POGIL.

Introduction

Learners bring into the classroom setting their ideas, concepts and prior knowledge about what is happening around them – all of which can make their learning easy or difficult (Chandran, Treagust, & Tobin, 1987; Lawson, 1983; Reynolds & Walberg, 1992). This prior knowledge the students bring forms the foundation of a constructivist approach because learning is the process of setting up associations between current knowledge and new instances of learning, and of integrating new knowledge with current knowledge, according to the constructivist approach (Brooks & Brooks, 1999; Perkins, 1999; Regis, Albertazzi, & Roletto, 1996). Yet, students' prior knowledge comprises alternative conceptions, which do not usually overlap with scientific concepts. Therefore, in order for meaningful and sustainable learning to occur, it is necessary to change these alternative conceptions (Smith, Blakeslee, & Anderson, 1993). As students' alternative conceptions are resistant to change, it is difficult to overcome the resistance using traditional teaching methods (Driver & Easly, 1978; Fisher, 1985; Hynd, McWhorter, Phares, & Suttles, 1994). As a result, conceptual change does not occur. For conceptual change to happen, it is recommended that approaches different from the traditional teacher-centred teaching approach could be used. One of the teaching methods that can help to change students' alternative conceptions is Process Oriented Guided Inquiry Learning (POGIL). POGIL has emerged on the basis of the benefits of constructivism, inquiry and cooperative learning – which could enable students to participate actively in structuring and understanding their own created knowledge (Bransford et al., 2000; Farrell, Moog, & Spencer, 1999; Moog, Lewis, & Bunce, 2006; as cited in Simonson & Shadle, 2013) (see Figure 1).

The POGIL method is a student-centred teaching philosophy, and it supports students' active participation in the learning process. In POGIL, students learn in small groups, through inquiry and by using activities that pursue the paradigm of learning cycles, which are specially designed. Although there are differences among the models developed on the basis of the inquiry learning approach, all of the models are generally based on the first model of the learning cycle (Atkin & Karplus, 1962). This model, which offers a general framework for organising constructivist learning activities, was developed using the theories of Piaget. The learning cycle has a three-phase structure, namely: the exploration phase, the concept invention phase, and the application phase (Abraham & Remer, 1986; Karplus, 1977) (Figure 1). Students respond to questions included in activities in a peer-led guided inquiry learning environment, in cooperation in POGIL, where peer learning becomes prominent. Initially, relatively easily questions are organised in a way that enables students to structure the concepts and to take into consideration the students' alternative conceptions, misunderstandings and inadequacies in terms of mental structures. Later on, the questions become relatively difficult, and are prepared in a way to ensure that the students acquire basic process skills (Moog, Creegan, Hanson, Spencer, & Straumanis, 2006).

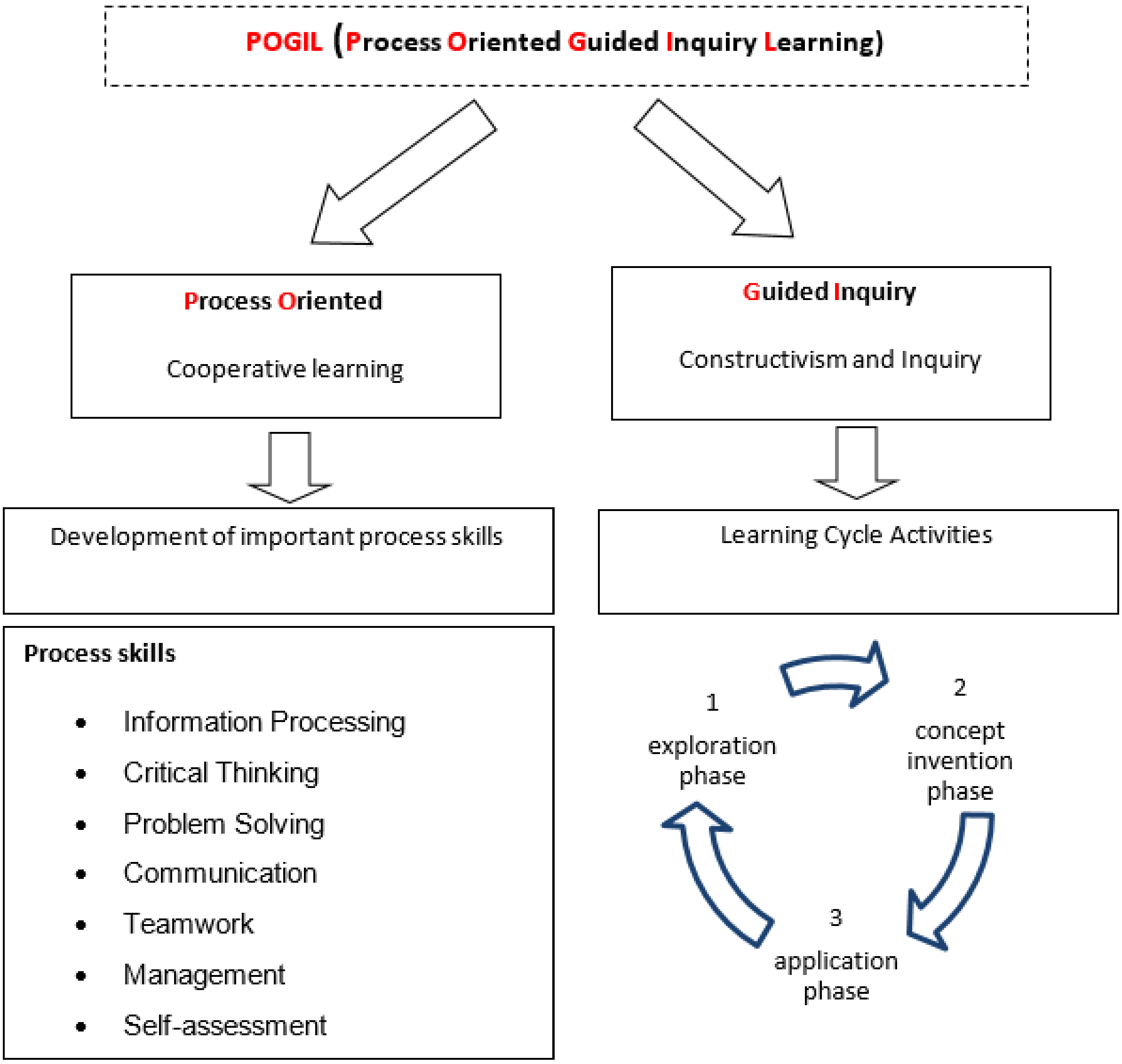


Figure 1. What is POGIL? Adapted from "Action research through the trial of appropriate POGIL activities with selected secondary science classes," by Terry Wales, n.d., Retrieved from http://www.stbedes.school.nz/wp-content/uploads/2012/02/Sabbatical.ppt

The only role the teacher plays in POGIL is as the facilitator of student learning. They do not directly intervene in groups. They only become involved in group discussions when a group requests, and then only to make sure that the scientific concepts are appropriately structured. All these phases are actualised on the basis of learning cycles in POGIL. In the exploration phase of the learning cycle, students explore the model in the activities, and they try to form an opinion or obtain information about the model without receiving any assistance. Subsequently, at the concept invention phase, students seek answers in groups for critical thinking questions. In this process, alternative conceptions that students have through discussion, appear. By working in groups and with the support and guidance of teachers it becomes possible through peer learning for learners to dispense with their alternative conceptions. Students following questions encouraging critical thinking will structure the new concept. In the application phase, the final phase of the learning cycle, students apply the concepts they have learnt to novel and diverse situations, thus reinforcing what they have learnt. At this stage, exercises and problems are prepared for students in POGIL. The most important detail to be noted is that the teacher is available in the classroom as the learning facilitator. In POGIL, both individual achievement and group achievement should be attained. Each student takes on various tasks through continuously changing roles within the groups. Groups have to reach a shared conclusion and a single truth (Hanson, 2006). Here too, students having alternative conceptions are persuaded by their friends in their groups, and are prevailed upon to change them. If those students are unable to perform these conceptual changes through peer learning in a cooperative group, the conceptions are changed with the teachers' support on the condition that it is not with peer learning. Since the POGIL method encourages all students to express themselves freely, students with alternative conceptions have a chance to discuss them. In a group, students help to explain the right scientific concepts to students with alternative concepts. In consequence, students' thought that the new concepts are intelligible, plausible and fruitful is made possible through cooperation to occur within groups. In this process a teacher joins a group as facilitator and listens to the students. If all of the students in a group have alternative conceptions, the teacher intervenes to explain the scientific concepts and change the alternative ones.

Studies about POGIL

A review of the literature shows that there are various studies relating to POGIL. The studies in question were carried out in relation to chemistry (Farrell *et al.*, 1999; Hanson & Wolfskill, 1998; Hinde & Kovac, 2001; Lewis & Lewis, 2005; 2008; Schroeder & Greenbowe, 2008; Spencer, 1999; 2000; 2006; Spencer & Moog, 2008), biology (Brown, 2010; Eberlein *et al.*, 2008), and mathematics (Rasmussen, &

Kwon, 2007; Rasmussen, Zandieh, & Wawro, 2009). It was found in a study conducted by Farrell *et al*. (1999) that students who were taught using POGIL attained higher achievement in chemistry than those who were taught using the traditional approach, and that they had positive attitudes towards the method used. Eberlein *et al*. (2008) compared three different teaching methods in science education - problem-based learning (PBL), POGIL and peer-led team learning. As a result, it was emphasised by the researchers that the POGIL method contributed more to the development of students' learning capabilities. Barthlow (2011), on the other hand, investigated the effects of POGIL method on changing alternative conceptions about the particulate nature of matter. Consequently, it was found that students taught through POGIL had fewer alternative conceptions than those taught using traditional teaching methods. The study by Wozniak (2012), however, analysed the effects of POGIL on students' understanding of biological classification. The research found that POGIL was influential in uncovering students' alternative conceptions and in changing them. A review of other studies in the literature concerning POGIL, shows that students' achievement levels have generally risen, and more sustained and in-depth learning has occurred through POGIL (Brown, 2010; Farrell *et al.*, 1999, Hanson & Wolfskill, 2000, Lewis & Lewis, 2005; Straumanis & Simons, 2008; Vacek, 2011; Vanags, Pammer, & Brinker, 2013). It was also found that students have positive opinions regarding POGIL learning environments (Brown, 2010; Conway, 2014; Eberlein *et al.*, 2008; Farrell *et al.*, 1999; Hinde & Kovac, 2001; Lewis & Lewis, 2005; Schroeder & Greenbowe, 2008; Soltis *et al.*, 2015).

Alternative conceptions about Electrochemistry

Oxidation and reduction, which are included in chemistry topics, are generally considered to be difficult concepts (Johnstone & Morrison, 1994, as cited in Brandriet, 2014). A review of the literature showed that students had difficulty in understanding the concepts of oxidation and reduction (Allsop & George, 1982, as cited in Brandriet, 2014; De Jong, Acampo, & Verdonk, 1995; Garnett & Treagust, 1992a; Ringnes, 1995; Rosenthal & Sanger, 2012; Schmidt & Volke, 2003). Furthermore, students have many alternative conceptions about the subject of electrochemistry, the foundations of which are formed by oxidation and reduction (Acar & Tarhan, 2007). Students may have different learning experiences during their first encounters with the topic of redox, for example, in the macroscopic, microscopic, symbolic and/or algebraic systems of representation (Harrison &

Treagust, 1998). The difficulties students encounter in terms of redox is related to the process and it is also conceptual. Conceptual difficulties are mainly in the subjects of electron transfer stemming from need for oxidation and reduction to occur together, differentiation in the oxidation and reduction tendencies of reactants in the redox reaction, and in the students' failure to fully understand the oxidation number (De Jong *et al.*, 1995; Garnett & Treagust, 1992a). The difficulties students typically encounter during a lesson on redox processes are:

1. A difficulty in determining whether or not reactions are redox reactions, as students choosing to use the criterion of electron transfer instead of the change in oxidation state cannot recognise equations where charge and electron changes are not clearly available as redox reactions (Ringnes, 1995).
2. Trying to determine redox reactions depending on changes occurring in the charges of polyatomic types in an equation (Garnett & Treagust, 1992a).

Another considerable difficulty stems from the fact that students do not understand the concepts of reductant and oxidant substance, as terms and some expressions incautiously used by teachers confuse the students (De Jong *et al.*, 1995). It was found through literature review that students had many misconceptions about electrochemistry (Acar & Tarhan, 2007; Al-Balushi, Ambusaidi, Al-Shuaili, & Taylor, 2012; Dindar, Bektas, & Celik, 2010; Ekiz, Kutucu, Akkuş, & Boz, 2011; Garnett, & Treagust, 1992a; 1992b; Karsli, & Calik, 2012; Ogude, & Bradley, 1994; Özkaya, 2002; Özkaya, Üce, & Şahin, 2003; Rosenthal & Sanger, 2012; Sanger, & Greenbowe, 1997a; 1997b; 1999; 2000; Schmidt, 1994; Schmidt, Marohn, & Harrison, 2007; Sumfleth, Stachelscheid, & Todtenhaupt, 1991; Şeşen, & Tarhan, 2013; Taşdelen, 2011; Yang, Andre, Greenbowe, & Tibell, 2003; Yilmaz, Erdem, & Morgil, 2002).

Aim of the Study

A review of literature clearly shows that the POGIL method generally increased students' achievement levels (Brown, 2010; Farrell *et al.*, 1999, Hanson & Wolfskill, 2000, Lewis & Lewis, 2005; Straumanis & Simons, 2008; Vacek, 2011; Vanags *et al.*, 2013). However, there are few studies that provide empirical evidence concerning the effectiveness of POGIL on students' alternative conceptions (Barthlow, 2011; Wozniak, 2012). Wozniak's study is related to alternative conceptions in biology and Barthlow's study is related to alternative conceptions in the particulate nature of matter in chemistry. A review of the literature indicates that

POGIL has a positive effect on achievement, with concrete evidence; however, there is a need for further study on the effect of POGIL in relation to students' alternative conceptions in chemistry. Thus, new studies are expected to satisfy the lack of POGIL's effect on alternative conceptions. Due to the fact that the number of studies comparing the effects of POGIL and traditional teaching on alternative conceptions is few, it is believed that this study will make a significant contribution to the literature. There is an enormous number of strategies and learning cycles in science education but in this study POGIL was used to decrease students' alternative conceptions in electrochemistry. This is because POGIL is a student-centred teaching method that supports students' active participation in learning processes. In addition, POGIL uses the advantages of constructivism, inquiry and cooperative learning. In addition, this study will contribute considerably to the literature about the effectiveness of POGIL on students' alternative conceptions in electrochemistry. Hence, the effects of POGIL on students' conceptual understanding of electrochemistry are analysed in this study with the following research problems:

1. Do the means of the students' gain scores in the experimental group and in the control group for the Electrochemistry Concept Test (ECT) differ significantly on the basis of the teaching method used?
2. At what levels are the students' conceptual understanding of electrochemistry in the experimental and control group?

Methodology

Study Design

This study used the nonequivalent control group design (Gay, Mills, & Airasian, 2012). The experimental and the control groups were administered in this study as a pre-test; the experimental and the control groups were administered as a pre-test; the experimental group had POGIL instruction, while the control group had traditional instruction and then the post-test was administered to both the experimental and the control groups. Two experimental groups and two control groups were randomly selected from four available groups (classes). Experimental groups were instructed using the POGIL method, while control groups were given traditional chemistry instruction. All groups received identical syllabus-prescribed learning content. The study was conducted over a six week semester.

Sample of Study

This study comprised 115 11th-grade students (61 boys and 54 girls) from four intact classes with two teachers. The study was conducted in a large urban district. Two of the classes were set as the experimental group (n= 56), and the remaining two classes were randomly set as the control group (n= 59). Two experimental and two control groups were selected because the researchers wanted the study to be conducted with a larger sample. Furthermore, assumptions of statistical analysis are better provided in large samples. The ages of the students ranged from 15 to 16 years old. The socioeconomic status (SES) of the students in the experimental and control groups was similar, with the majority of the students coming from mid-SES to upper-SES families. Two chemistry teachers were included in the research. Each teacher had one experimental group and one control group. This prevented the treatment diffusion factor, which is one of the factors affecting the validity of the study. Prior to the teaching the lessons in experimental groups, the researcher and the teachers exchanged information about POGIL and that day's activity.

Instrument

The Electrochemistry Concept Test (ECT) was developed by authors. The purpose of ECT is to determine students' conceptual understanding of electrochemistry, and to reveal alternative conceptions about the subject. The ECT included 19 questions. The questions in ECT are not similar in POGIL exercises. The ECT comprised three tier multiple choice questions and the POGIL exercise included open-ended questions and problems. All of the questions were prepared using the course books that the schools had given to the students. The questions in the control group exercises were prepared by their teacher based on the traditional teaching method and these questions were similar to the questions in the POGIL exercises. The questions prepared were related to reduction, oxidation, electrodes, electrochemical cells, galvanic cells, concentration cells, electrolysis, and Faraday's laws. Each was a three-tier question. The first tier of each question was a multiple-choice question, and had five alternatives. The second tier again had five alternatives, but here students were asked to state the reason for their choice in the first stage. The distractors in the second tier were generally the alternative conceptions concerning electrochemistry. In the third tier, students were asked to state how confident they were in terms of their answers to the questions in the first and second tiers. To calculate total scores, the answers of students of each question in the first, second and third tier (confidence level) were evaluated. If the answer of the students in the third tier was 'I am sure' for their incorrect responses in first and/or second tier, this indicated that these students have alternative conceptions; however, if the answer of the students in the third tier was 'I am not sure' for their incorrect responses in first and/or second tier, this indicated that these students lacked knowledge.

Two experts in chemistry education reviewed each item and the content validity of the ECT. The items were revised based on suggestions submitted by the experts. Prior to the administration the ECT as a pre-test, a pilot study with 268 students (excluding the students in the experimental and control group) was conducted to assess the face and content validity of the test. The students in the pilot study were 11th-grade students from similar mid-SES to upper-SES families. The items were revised and some rearranged, according to the results of the pilot study. In the ECT evaluation, students who had answered the first and second stages of the test correctly and who had been sure of their answers received 1 point; and those who had answered one or both stages of the test incorrectly received 0 point (Arslan, Çiğdemoğlu, & Moseley, 2012; Gürcay & Gülbaş, 2015; Pesman & Eryılmaz, 2010). Following reliability analyses, the Cronbach Alpha value was found to be 0.810 for the 19-item test.

Procedures

The experimental and control groups both received 36 hours of teaching. Each group instruction comprised four 45-minute sessions per week and each POGIL activity was one 45-minute session, only for critical thinking questions (except for exercises and problems in POGIL activities). Two high school teachers participated in the research. Both teachers used the POGIL method in their experimental group and the traditional teaching method in their control group. The researchers qualified in science and chemistry education prepared the POGIL activities. Experts in science education and chemistry teachers checked the POGIL activities, conducted various scientific studies in teaching and learning approaches. During the two weeks prior to the treatment, the teachers were informed about POGIL activities and their use, over a period totalling eight hours. Teachers prepared POGIL activities relating to different chemistry topics. Following this, the researchers provided samples of different POGIL activities in the literature. In this process, the researchers provided more information and details about POGIL and the application of POGIL in the classroom.

Treatment in the Experimental Group

The experimental group of students were taught using the POGIL method. POGIL is a learner-centered approach that focuses on small groups of students (4-5) engaging in inquiry-based learning activities. The students in the experimental group worked with POGIL activities designed on the basis of the three-phase structure of the Learning Cycle; namely, the exploration phase; the concept invention phase and application phase.

Prior to the application, sessions were held with the chemistry teachers in the schools included in the study and the teachers were informed about the POGIL method. Subsequently, taking the teachers' opinions into account, the final shape was given to electrochemistry course, materials were prepared using POGIL and these materials were given to the teachers for them to use in their teaching. First of all, the teachers informed the students in the experimental group about the POGIL method, the concept maps and the preparation of the lotus blossom technique. The lotus blossom technique is a data collection tool to determine students' ideas, cognitive structures, and understanding in relation to a concept (Palıcıca, Gavrılă, & Boacă, 2010; Yaqoob, 2007). Groups were formed from each experimental group in accordance with cooperative learning method procedures. These groups, who would study in the classroom setting, were formed heterogeneously, according to achievement levels (high achievers, middle achievers, and low achievers), based on the results of the previous chemistry exam and then the application began.

The students in the experimental group, who would be taught using the POGIL method, were told about their roles in their groups (managers, presenters, recorder, and reflectors etc.). It was explained to them that they would take turns in playing these roles for each activity. As well as their tasks, the rules they would follow were also explained to them. They were told that while responding to critical thinking questions in particular the group should have shared views. Furthermore, in order to be able to follow the process effectively, each group was asked to prepare a group file containing their work and the answers they gave to the questions.

In order to contribute to the evaluation of the POGIL method, quizzes would be given to students at the beginning of each lesson. In this study, concept maps and the lotus blossom technique were also used, so that the students could assess their learning process and see their mistakes and their progress. At the end of each lesson the students were given five minutes to prepare the concept maps and lotus blossoms, after which they were collected. The students were given no extra time.

The students studied cooperatively in the groups during the prepared activities, on the basis of the three-phase structure (exploration phase, concept invention phase and application phase) of the learning cycle. Meanwhile, the teacher walked around the classroom and checked the group's shared answers as shown in the notes taken by the recorders. When necessary, the teacher intervened and guided the students in their learning process. The students were asked to respond only to the critical thinking questions included in the activities.

The teacher also encouraged interaction between the groups. From time to time, the teacher asked a group to explain their answers to the critical thinking questions to the whole class. In this way, the groups had the opportunity to compare their answers and thus dispense with their contradictions. Certain groups sometimes took on the role of consultant for other groups and helped them to understand the activities.

POGIL Activities Used in the Study

The opinions of a board of experts comprising chemistry educators and chemistry teachers were obtained for the preparation of the POGIL activities used in this study. The necessary arrangements for the activities were made in accordance with their opinions. A total of nine POGIL activities were prepared for the study, in relation to subjects including reduction, oxidation, electrodes, electrochemical cells, galvanic cells, concentration cells, electrolysis, and Faraday's laws. All the activities were designed by the researchers. A varied number of models and critical thinking questions were developed for each activity. In addition to this, exercises and problems were prepared at the end of each activity. A sample activity is shown in Appendix A.

Treatment in the Control Group

The control group students were taught using traditional chemistry teaching methods (teacher-centered approach). Although the Turkish chemistry curriculum suggests constructivist learning environments to enhance learning and support conceptual change, Turkish chemistry teachers do not hold positive beliefs about implementing constructivist teaching methods in schools, such as problem-based learning, project-based learning and inquiry based learning. Therefore, many chemistry teachers in Turkey use traditional chemistry instruction. Traditional instruction is a teacher-directed strategy, based on teacher's explanations, discussions, and textbooks. Management and responsibility for learning are teacher-centered. This traditional teaching views students as the passive recipients of information. In the control group, lessons were taught in the traditional chemistry teaching method in the form of lectures and questioning. A teacher-centered teaching approach was adopted in the process of learning the concepts related to reduction, oxidation, electrodes, electrochemical cells, galvanic cells, concentration cells, electrolysis, and Faraday's Laws. Before attending class, the students studied the subjects in their course books. The classroom environment and the whole learning process was structured by the teachers. The teachers required the students to take notes, they explained the concepts using the blackboard, drew figures related to electrochemistry, prepared charts about galvanic cells and concentration cells, and solved sample problems. The teachers asked the students questions and required them to participate in discussions that were always under the teachers' control. The coursework material were the examples, figures and pictures contained in the worksheets and course books.

Also, in the control group, concept maps and mini quizzes were used as an assessment tool to examine the students' understanding of electrochemistry concepts. Apart from the POGIL activities, all the activities in the experimental and control groups were similar. Instead of POGIL activities being used, the teachers made activities/materials based on traditional teaching methods.

Results

The results obtained from the study were evaluated in accordance with the research questions. Prior to gain score analysis, an independent sample t test analysis was used to compare the mean differences between the experimental and control group with regard to the students' pre-test scores on their understanding of the electrochemistry test. Results of the independent sample t-test analyses showed that there was a significant difference between the experimental group (M = 6.82, SD = 2.89) and control group ($M = 4.53$, $SD = 2.76$; t (113) $=4.36$, $p=0.000$, *two-tailed*). The magnitude of the differences in the means was large (eta squared = .144). Therefore, the confounding effect of students' pre-test scores should be controlled in the following analyses. In order to control the confounding effect of students' pre-test scores, gain scores were used to examine the effect of the teaching method.

Comparison of Gain Scores of Students (Results for First Research Question)

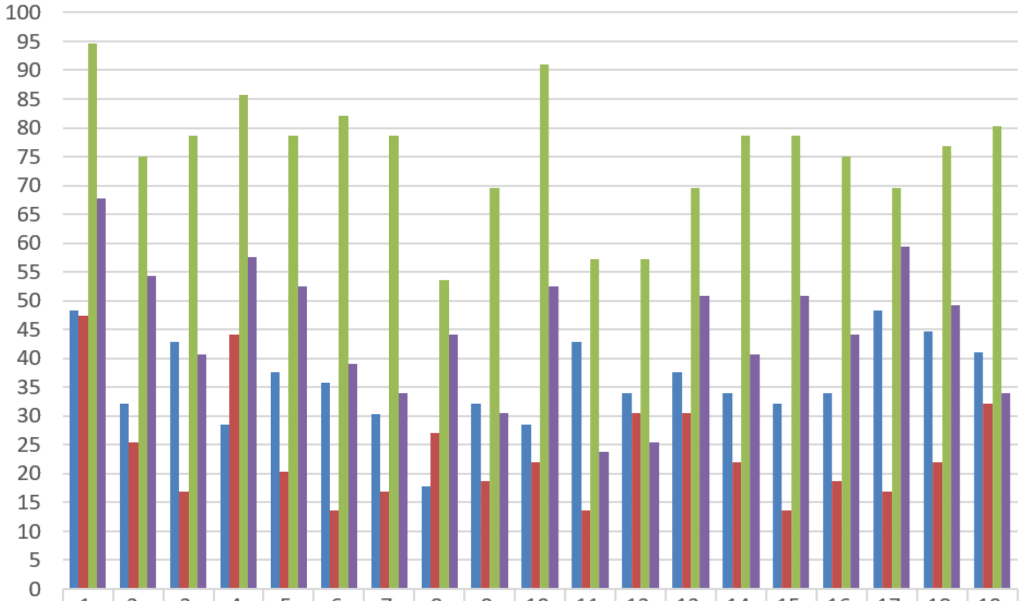
In order to solve the first research problem, the independent samples t-test analysis was performed to compare the means of the gain scores obtained from the difference between the students' pre- and post-test scores. The Levene's test results were checked and it was found that the significance level was greater than p= .05, and that the assumption of equal variance was satisfied. The independent samples t-test results showed that there was a significant mean difference between the experimental and control group students with regard to the means of their gain scores, $t(113)=5.65$, $p<0.01$. The experimental group students' gain score average ($M=7.48$), was higher than those of control group students ($M=3.98$). The eta square value calculated was $\eta 2=.22$. Accordingly, the magnitude of the differences in the means of gain scores was quite high (see Table 1).

Table 1. Independent Samples t-test Results

	Group	N	Mean	Std. Deviation	Levene's Test		t	df	Sig.
					F	Sig.			
Gain Score	Experimental	56	7.48	3.09	.65	.42	5.65	113	.000
	Control	59	3.98	3.53					

Students' Levels of Conceptual Understanding (Results for Second Research Question)

Students' ECT post-test answers were examined at the end of the application, so as to check the experimental and control group students' understanding of electrochemistry in relation to a solution for the second research problem. In consequence, the rates of the ECT post-test correct answers of the experimental and control group students were compared, and the findings were shown in Figure 2. An examination of the percentages given in Figure 2 makes it clear that the percentage of experimental group students 'correct answers to questions 8, 11 and 12 in the ECT post-test is below 70%. The students in the experimental group had the highest rate of mistakes in these three questions. Therefore, these questions were examined. Appendix B shows the percentage of students' answers to a sample question in the test.



	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Exp.PreTest	48	32	43	29	38	36	30	18	32	29	43	34	38	34	32	34	48	45	41
Cont.Pretest	47	25	17	44	20	14	17	27	19	22	14	31	31	22	14	19	17	22	32
Exp.Posttest	95	75	79	86	79	82	79	54	70	91	57	57	70	79	79	75	70	77	80
Cont.Posttest	68	54	41	58	53	39	34	44	31	53	24	25	51	41	51	44	59	49	34

Figure 2. A comparison of the rates of experimental and control group students' correct answers

On examining the questions in ECT, it was found that students had various alternative conceptions (Table 2). In question 8, an attempt was made determine whether or not students had alternative conceptions as *"the potential of standard hydrogen electrode is found as a result of experimental procedures"*. While 57.14% of the students in the experimental group responded correctly to the first two stages of this question, 54% said that they were not sure of their answers. On examining the answers given by the students in the control group, the rate was found to fall from 45.76% to 44%. To the statement "that standard electrode potentials for $H_{2(1atm)}/H^{+}_{(1M)}$ is zero was found in consequence of experimental measurements", 73.21% of the experimental group students and 57.63% of the control group students gave correct answers. It was found in the post-test that 10.71% of the experimental group students and 16.95% of the control group students had an alternative conception as *"standard hydrogen electrode was chosen as the standard reference electrode, and standard electrode potentials of this electrode at 298,15 K (25 °C) was regarded as (E°) 0,0000 V"*. Besides, 71.4% of the experimental group students and 13.56% of the control group students had alternative conceptions as "$Mg^{2+}_{(aq)}$ +

$2e^- \rightarrow Mg_{(s)}$ reduction half-equations occur in cathode, and $H_{2(g)} \rightarrow 2H^+ + 2e^-$ oxidation half equations occur in anode"; while 10.71% of the experimental group students and 6.78% of the control group students had alternative conceptions as "*E^0 value of $H_{2(1\ atm)}/H^+_{(1\ M)}$ is zero and this is derived from the chemistry of H^+ and H_2*". One of the distractors used in this question, the alternative stating "since half-cell potentials are the values which are obtained by measuring, they are precise and are used in calculating half-cells" was chosen by 7.14% of the students in the experimental group and 11.86% of the students in the control group. At the second stage of the question, the proportion of correct answers was 64.29% in the experimental group, and 50.85% in the control group.

In question 11, an attempt was made to determine whether or not students had alternative conceptions about concentration cells. 60.71% of the experimental group students answered the first stage of this question correctly while 57% of the students said that they were sure of their answers to the first two stages of the question. On examining the answers given by control group students, it was found that the proportion fall from 33.90% to 24%. To the statement "The direction of electron flow is from Ag electrode in the first container to Ag electrode in the second container in the external circuit" 83.93% of the experimental group students and 42.37% of the control group students gave correct answers. In the ECT post-test, 8.93% of the experimental group students and 11.86% of the control group students were found to have alternative conceptions as "the potential of a battery is not dependent on the concentration of anode and cathode containers. Electricity power is needed in order for the battery to work, and the potential of the battery is negative according to Nernst equation". And on examining the other distractors, it was found that 12.50% of the experimental group students and 6.78% of the control group students had alternative conceptions as "because there are no net reactions in concentration cells, reaction quotient cannot be calculated."; and 5.36% of the experimental group students and 8.47% of the control group students had alternative conceptions as "cell potential in concentration cells is independent of the concentration of half-cell solutions". Besides, the alternative "the direction of electron flow is independent of the concentration of solutions in cells" was chosen only by 16.95% of the control group students. The proportion of correct answers at the second stage was 73.21% in the experimental group and 49.15% in the control group.

In question 12, an attempt was made to determine whether or not students had alternative conceptions about galvanic cells. While 75% of the experimental group students answered the first two stages of the question correctly, 57% of them said that they were sure of their answers. As to the answers given by control group students, it was found that the proportion dropped from 28.81% to 25%. To the statement "the direction of spontaneous change is that of the forward reaction", 96.64% of the experimental group students and 66.10% of the control group students responded correctly. In the ECT post-test, 1.79% of the experimental group students and 3.39 % of the control group students had alternative conceptions as "electrons enter the electrolyte from the cathode, they are carried by electrolyte and salt bridge, and then they complete the circuit and they emerge in the anode". 1.79% of the experimental group students and 5.08% of the control group students based their answers to the statement "electrons can move in solutions just like ions do" and 3.57% of the experimental group students and 25.42% of the control group students based their answers to the statement "conductivity in solutions is ensured only through the movement of negatively charged ions". Another distractor, one of the alternatives, "anode is always on the left" was chosen by 8.93% of the experimental group students and 15.25% of the control group students. The proportion of correct answers at the second stage of the question was found to be 78.57% in the experimental group and 44.07% in the control group.

Table 2. Alternative conceptions Found by Means of ECT Post-test in the Experimental and Control Groups, and Their Percentages

Student's alternative conceptions	**Question**	**Post-test Experimental group**	**Post-test Control group**
		%	**%**
Conductivity in solutions is ensured only through the movement of negatively charged ions	12	3.57	25.42
Electrons can move in solutions just like ions do.	6	1.79	5.08
Anode is always on the left.	12	8.93	15.25
The place of anode and cathode is determined by the physical placement of half-cells.	5	7.14	5.08
Only negatively charged ions form a flow of current in electrolyte and salt bridge.	12	1.79	6.78
Electrons flow in aqueous solutions without assistance of ions.	12	1.79	11.86

Electrons enter the electrolyte from the cathode, they are carried by electrolyte and salt bridge, and then they complete the circuit and they emerge in the anode.	10	1.79	3.39
Anode is positively charged, because it releases electrons; cathode is negatively charged because it attracts electrons.	12	.00	6.78
Electrons' direction of flow is independent of the concentration of solutions in concentration cells.	11	.00	16.95
In a voltaic battery cell, electrons flow from cathode to anode through a conducting wire.	7	3.57	5.08
Anions in the electrolytes attract electrons and transfer them into cathodes.	10	1.79	13.56
Since half-cell potentials are the values which are obtained by measuring, they are precise and are used in calculating half-cells	8	7.14	11.86
Changes in the charges of OH-, BiO3- and Cr(OH)4- ions determine the number of attracted and released electrons.	4	.00	8.47
Oxidation is the addition of oxygen whereas reduction is moving the oxygen away.	4	.00	11.86
Reduction half reaction for the reaction $2OH^- + 3BiO_3^- + 2Cr(OH)_4^- \rightarrow 3BiO_2^- + 2CrO_4^{2-} + 5H_2O$ is $2Cr(OH)_4^- + 1e^- \rightarrow 2CrO_4^{2}-$	4	7.14	13.56
It was found that standard electrode potential for $H_{2(1atm)}/H^+_{(1M)}$ was zero in consequence of experimental measurements.	8	26.79	25.42

Students' responses to ECT post-test were analysed for the second sub-problem of the research. In consequence, it was found that the students in the experimental and in the control group in this research also had alternative conceptions similar to the ones found earlier in the literature. Some of the alternative conceptions found in this study are as in the following:

- Changes in the charge of polyatomic types in an equation can be used in describing redox equations (Garnett, & Treagust, 1992a; 1992b).
- Oxidation is the addition of oxygen whereas reduction is moving the oxygen away (Garnett, & Treagust, 1992a;1992b; Sanger & Greenbowe, 1997a).
- The standard electrode potential for $H_{2(1atm)}/H^+_{(1M)}$ was zero was found in consequence of experimental measurements (Canpolat et al., 2004; Garnett & Treagust, 1992a; 1992b; Sanger & Greenbowe, 1997a; 1999).

- Inert electrodes can be oxidized or reduced (Sanger & Greenbowe, 1997a).
- Half-cell potentials are the values which are obtained by measuring, and they are precise and are used in calculating half-cells (Sanger & Greenbowe, 1997a).
- In a voltaic battery cell, electrons flow from cathode to anode through a conducting wire (Sanger & Greenbowe, 1997b; Taşdelen, 2011).
- Electrons are carried by electrolytes (Canpolat et al., 2004; Garnett & Treagust, 1992a; 1992b; Sanger & Greenbowe, 1997b; 1999).
- Electrons are carried by electrolyte and salt bridge (Acar & Tarhan, 2007; Garnett & Treagust, 1992a; 1992b; Taşdelen, 2011; Yang et al., 2003).
- The place of anode and cathode is determined by the physical placement of half-cells (Acar & Tarhan, 2007; Sanger & Greenbowe, 1997a; Taşdelen, 2011).
- Anode is positively charged, because it releases electrons; cathode is negatively charged because it attracts electrons (Acar & Tarhan, 2007; Garnett & Treagust, 1992a; 1992b; Taşdelen, 2011; Yang et al., 2003).
- Only negatively charged ions form a flow of current in electrolyte and salt bridge (Acar & Tarhan, 2007; Sanger & Greenbowe, 1997b; Yang et al., 2003).
- Electrons' direction of flow is independent of the concentration of solutions in concentration cells (Sanger & Greenbowe, 1997a).
- In concentration cells, battery potential is independent of the concentration of solutions in half-cells (Canpolat et al., 2004; Sanger & Greenbowe, 1997b; Taşdelen, 2011).

Discussion

The main purpose of this study was to determine the effectiveness of POGIL on 11th grade students' misconceptions relating to electrochemistry. Results showed that POGIL resulted in a significantly better acquisition of scientific conceptions than did traditional chemistry teaching with regard to electrochemistry and in changing alternative conceptions. Based on analysis of the results for the first research question, it may be said that POGIL activities were effective in rectifying some of the students' alternative conceptions relating to electrochemistry. In a review of the relevant literature we did not find many studies on POGIL activities that changed students' alternative conceptions. The conclusion reached by Barthlow (2011) and

Wozniak (2012) that the POGIL method was influential in changing students' misconceptions at least partially, was parallel to the conclusion reached in this study. A review of in the literature relating to other studies conducted on POGIL showed that students' achievement levels increased with the use of the POGIL method, and through it they attained permanent and in-depth learning (Brown, 2010; Farrell *et al.*, 1999, Hanson & Wolfskill, 2000, Lewis & Lewis, 2005; Straumanis & Simons, 2008; Vacek, 2011; Vanags *et al.*, 2013). Hein (2012) found that students taught using the POGIL method had better organic chemistry exam results than those who had been taught through traditional teaching methods. The researcher stated that there was a connection between students' achievement and the method employed. The students in the experimental group said that the learning environment provided by POGIL was better than that provided by the traditional approach. In Campbell's (2014) study it was found that laboratory activities combined by POGIL were more influential than traditional lab techniques in facilitating students' concept learning in the biochemistry laboratory. Conversely, some studies in the literature have found that POGIL and traditional teaching raised students' achievement levels equally (Judd, 2014; Murphy, Picione & Home, 2010). Nevertheless, methods in which the learners are passive usually contribute less to the development of students' metacognition and critical thinking skills. Learning methods such as POGIL, in which learners are active, ensure that students build and structure their own knowledge and develop their higher order scientific thinking skills and conceptual understanding (Varma-Nelson & Coppola, 2005). Student-centred teaching methods increase students' academic achievement and facilitate the development of their self-concept and positive attitudes towards a course (Johnson, Johnson, & Smith, 1998; Stevens & Slavin, 1995).

It is not an easy process for students having alternative conceptions to learn a new concept as adding new knowledge into the existing cognitive structure is. For students, learning with removing of alternative concepts means re-organizing their existing cognitive structure. Conceptual change is a difficult and long process. Therefore, teaching methods to be used should have the properties to eliminate students' alternative conceptions. Since their alternative conceptions were configured through their experiences, it is not usually easy to change those alternative conceptions, and even after formal education those alternative conceptions continue existing in students' cognitive structure. Therefore, teaching methods and techniques should be designed to enable students to focus on their pre-conceptions and to eliminate probable alternative conceptions.

The second purpose of this study was to determine the experimental and control group students' levels of conceptual understanding in electrochemistry. It was found in this research that the students in the experimental group had fewer alternative conceptions than the students in the control group in terms of electrochemistry. On comparing the experimental and the control group students' answers to the questions in the ECT post-test, it was found that experimental group students' proportion of correct answers was higher in all questions (Figure 2). The reason for this is that POGIL ensures students' in-class participation and thus supports their learning (Brown, 2010; Farrell *et al.*, 1999; Minderhout & Loertscher, 2007; Straumanis & Simons, 2008; Vanags *et al.*, 2013). It is also because POGIL is a method in which cooperative learning and inquiry learning are used in combination. Inquiry-based activities ensure that students structure their new knowledge and test their thoughts, and they also support the students' formation of evidence-based thoughts and the critical questioning of these thoughts.

Cooperative learning as well as inquiry-based learning plays an important role in POGIL. Students learn more, understand more and remember more in cooperative learning environments. They have more positive opinions about their classmates as a result of working together and develop positive attitudes towards a course and a teacher. Students learning within a group acquire basic processing skills, such as communication, team work, problem solving, and analytical and critical thinking (Johnson, Johnson, & Smith, 1991). Group members' knowledge, perceptions, ideas and differences in thought processes lead to disagreements between them. If these conflicts are managed in a constructive way, through social and cooperative skills, such as discussion and inquiry, students can begin to research in order to acquire more information, and consequently restructure their knowledge. At the end of the process, in addition to changing their alternative conceptions, more meaningful learning and knowledge retention will occur. Students will also use more critical thinking and a higher order of thinking skills in this process (Cooper, 2005; Johnson, Johnson, & Smith, 1991). Cullen and Pentecost (2011) suggest that discussions in small groups and the facilitating role of teachers in the classroom will increase students' conceptual understanding. The researchers also indicated that students structured their knowledge and changed their misconceptions during their peer-group discussions. Consequently, POGIL yielded more fruitful results than with traditional teaching approaches in changing alternative conceptions. Taking these results into consideration, it may also be used in subjects other than electrochemistry and in courses other than chemistry.

Methods based on the student-centred constructivist approach should be used for students' meaningful learning and in structuring their own knowledge. The POGIL method, which is used in this study, ensures an activity-based education that enables students to structure their own knowledge. Abraham (2015) states that the POGIL method encourages students to structure their own knowledge. The research also emphasises that guided inquiry activities support understanding based on learning cycles. The critical thinking questions included in POGIL activities help students to formulate the necessary concepts and guide them towards reaching an appropriate conclusion. The questions are simple at first, in order to increase the students' self-confidence; however, they gradually become more difficult. Difficult questions require higher order thinking and the integration of concepts with more knowledge. At the end of each activity, students assess both the task and their progress (Hanson & Wolfskill, 2000). In this process, students structure their own knowledge and have in-group discussions, so as to rectify their alternative conceptions at the same time.

Conclusion

In the light of these findings, it could be concluded that POGIL has a positive effect on students' alternative conceptions about electrochemistry. According to analysis of the students' ECT post-test answers, results showed that after the intervention, students in experimental groups had less misconceptions and had gained a more significant improvement than the students in the control group. Because, inquiry activities ensures the physical and mental participation of students in the learning process. Therefore, teachers should favour learning methods that are based on inquiry and for which they will assume responsibility for their students' learning. A review of the literature demonstrates that there are few studies relating to the effects of POGIL on students' alternative conceptions. For this reason, it is recommended that research is conducted into the effects of POGIL on changing students' alternative conceptions about chemistry, as well as in other subjects. This current study was conducted with eleventh graders but the study group could be changed and the effects of POGIL can be analysed using other grade levels. One hundred and fifteen students were included in this study. The size of the sample could be increased and the probable results could be researched.

Notes

‡ This study is a part of PhD Thesis entitled "Investigation of Students' Conceptual Understanding of Electrochemistry and Self-Regulated Learning Skills in Process Oriented Guided Inquiry Learning Environment" (Şen, 2015) completed within Hacettepe University Graduate School of Educational Sciences. This study was supported by Research Fund of Hacettepe University. Project Number: SDK-2015-5443.

References

Abraham, M. R. (2005). Inquiry and the learning cycle approach. N. J. Pienta, M. M. Cooper and T. J. Greenbowe (Eds.) *Chemists' guide to effective teaching*. Upper Saddle River, NJ: Prentice Hall.

Abraham, M.R., & Renner, J.W. (1986). The sequence of learning cycle activities in high school chemistry. *Journal of research in Science teaching*, *23*(2),121-143.

Acar, B., & Tarhan, L. (2007). Effect of cooperative learning strategies on students' understanding of concepts in electrochemistry. *International Journal of Science and Mathematics Education, 5*(2), 349-373.

Al-Balushi, S. M., Ambusaidi, A. K., Al-Shuaili, A. H., & Taylor, N. (2012). Omani twelfth grade students' most common misconceptions in chemistry. *Science Education International*, *23*(3), 221-240.

Arslan, H. Ö., Çiğdemoğlu, C., & Moseley, C. (2012). A three-tier diagnostic test to assess pre-service teachers' misconceptions about global warming, greenhouse effect, ozone layer depletion, and acid rain. *International Journal of Science Education*, *34*(11), 1667–1686.

Atkin, J.M. & Karplus, R. (1962). Discovery or invention? *The Science Teacher*, *29*(5), 45-51.

Barthlow, M. J. (2011). *The effectiveness of process oriented guided inquiry learning to reduce alternate conceptions in secondary chemistry* (Order No. 3466432). Available from ProQuest Dissertations & Theses Global. (885000602). Retrieved from http://search.proquest.com/docview/885000602?accountid=11248

Brandriet, A. R. (2014). *Investigating students' understandings of the symbolic, macroscopic, and particulate domains of oxidation-reduction and the development of the redox concept inventory* (Order No. 3670808). Available from ProQuest Dissertations & Theses Global. (1646484044). Retrieved from http://search.proquest.com/docview/1646484044?accountid=11248

Bransford, J. D., Brown, A. L., Cocking, R. R., Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (2000). *How people learn: Brain, mind, experience, and school.* Washington, D.C.: National Academy Press.

Brooks, J.G., & Brooks, M.G. (1999). *In search of understanding: The case for constructivist classroom.* Alexandria, Virginia: Association for Supervision and Curriculum Development.

Brown, P.J.P. (2010). Process-oriented guided-inquiry learning in an introductory anatomy and physiology course with a diverse student population. *Advances in Physiology Education, 34*, 150-155.

Campbell, N. (2014). Process oriented guided inquiry learning to enhance learning of concepts in a biochemistry lab. *The FASEB Journal*, *28*(1 Supplement), 618-9.

Chandran, S., Treagust, D. F., & Tobin, K. (1987). The role of cognitive factors in chemistry achievement. *Journal of Research in Science Teaching*, *24*(2), 145-160.

Conway, C. J. (2014). Effects of guided inquiry versus lecture instruction on final grade distribution in a one-semester organic and biochemistry course. *Journal of Chemical Education*, *91*, 480−483.

Cooper, M. M. (2005). An introduction to small-group learning. In N. J. Pienta, M. M. Cooper, & T. J. Greenbowe (Eds.), *Chemists' guide to effective teaching* (117-28). Upper Saddle River, NJ: Pearson Prentice Hall.

Cullen D. M., & Pentecost T. C. (2011). A model approach to the electrochemical cell: An inquiry activity. *Journal of Chemical Education, 88*(11), 1562–1564.

De Jong, O., Acampo, J., & Verdonk, A. (1995). Problems in teaching the topic of redox reactions: Actions and conceptions of chemistry teachers. Journal of *Research in Science Teaching,32*(10), 1097–1110

Dindar, A., Bektaş, O. & Yalçın Çelik, A. (2010). What are the pre-service chemistry teachers' explanations on chemistry topics? I*nternational Journal of Research in Teacher Education (IJRTE), 1*(3), (32-41).

Driver, R. & Easley, J. (1978). Pupils and paradigms: A review of the literature related to concept development in adolescent science students. *Studies in Science Education, 5*(1), 61–84.

Eberlein, T. Kampmeier, J., Minderhout, V., Moog, R.S., Platt, T., Varma-Nelson, P. & White, H.B. (2008). Pedagogies of engagement in science: A comparison of PBL, POGIL, and PLTL. *Biochemistry and Molecular Biology Education, 36*, 262-273.

Ekiz, B., Kutucu, E. S., Akkuş, H., & Boz, Y. (2011). *Pre-service chemistry teachers' understanding of electrolytic cells.* Retrieved from http://www.esera.org/media/ebook/strand12/ebook-esera2011_EKIZ-12.pdf

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education, 76*(4), 570-574.

Fisher, K. M. (1985). A misconception in biology: Amino acids and translation. *Journal of Research in Science Teaching, 22*(1), 53-62.

Garnett, P. J. & Treagust, D. F. (1992a). Conceptual difficulties experienced by senior high school students of electrochemistry: Electric circuits and oxidation-reduction equations. *Journal of Research in Science Teaching, 29*(2), 121–142.

Garnett, P. J. & Treagust, D. F. (1992b). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29*(10), 1079-1099.

Gay, L.R., Mills, G. E., & Airasian, P. (2012). *Educational research: Competencies for analysis and applications.* Upper Saddle River, NJ: Pearson.

Gürcay, D., & Gülbaş, E. (2015). Development of three-tier heat, temperature and internal energy diagnostic test. *Research in Science & Technological Education, 33*(2), 197-217.

Hanson, D. M. (2006). *Instructor's guide to process-oriented guided-inquiry learning*. Lisle, IL: Pacific Crest.

Hanson, D., & Wolfskill, T. (1998). Improving the teaching/learning process in general chemistry: Report on the 1997 Stony Brook general chemistry teaching workshop. *Journal of Chemical Education, 75*(2), 143-146.

Hanson, D., & Wolfskill, T. (2000). Process workshops: A new model for instruction. *Journal of Chemical Education, 77*(1), 120-130.

Harrison, A. G., & Treagust, D. F. (1998). Modeling in science lessons: Are there better ways to learn with models? *School Science and Mathematics, 98*(8), 420–429.

Hein, S.M. (2012). Positive impacts of using POGIL in organic chemistry. *Journal of Chemical Education, 89*(7), 860–864.

Hinde, R.J., & Kovac, J. (2001). Student active learning methods in physical chemistry. *Journal of Chemical Education, 78*, 93 – 99.

Hynd, C. R., McWhorter, J. Y., Phares, V. L. & Suttles, C. W. (1994). The role of instruction in conceptual change in high school physics topics. *Journal of Research in Science Teaching, 31*(9), 933-946.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991). *Active learning: Cooperation in the college classroom*. Edina, MN: Interaction.

Judd, W. L. (2014). *The effects of process oriented guided inquiry learning on secondary student ACT science scores* (Order No. 3582793). Available from ProQuest Dissertations & Theses Global. (1609382010). Retrieved from http://search.proquest.com/docview/1609382010?accountid=11248

Karplus, R. (1977). Science teaching and development of reasoning. *Journal of Reseacrh in Science Teaching, 14*(2), 169-75.

Karsli, F. & Calik, M. (2012). Can Freshman Science Student Teachers' Alternative Conceptions of 'Electrochemical Cells' Be Fully Diminished?. *Asian Journal of Chemistry, 24*(2), 485-491.

Lawson, A. E. (1983). Predicting science achievement: The role of developmental level, disembedding ability, mental capacity, prior knowledge, and beliefs. *Journal of Research in Science Teaching, 20*(2), 117-129.

Lewis, S.E., & Lewis, J. E. (2005). Departing from lectures: An evaluation of a peer-led guided inquiry alternative. *Journal of Chemistry Education, 82*, 135 – 139.

Lewis, S.E., & Lewis, J.E. (2008). Seeking effectiveness and equity in a large college chemistry course: An HLM investigation of peer-led guided inquiry. *Journal of Research in Science Teaching, 45*, 794-811.

Minderhout, V., & Loertscher, J. (2007). Lecture-free biochemistry. *Biochemistry and Molecular Biology Education, 35*, 172 – 180.

Moog, R. S., Creegan, F. J., Hanson, D. M., Spencer, J. N., & Straumanis, A. R. (2006). Process-oriented guided inquiry learning: POGIL and the POGIL project. *Metropolitan Universities Journal, 17*(4), 41-52.

Murphy, K. L., Picione, J., & Holme, T. A. (2010). Data-driven ımplementation and adaptation of new teaching methodologies. *Journal of College Science Teaching, 40*(2), 80-86.

Ogude, A. N., & Bradley, J. D. (1994). Ionic conduction and electrical neutrality in operating electrochemical cells: Pre-college and college student interpretations. *Journal of Chemical Education, 71*(1), 29-34.

Özkaya, A. R. (2002). Conceptual difficulties experienced by prospective teachers in electrochemistry: Half-cell potential, cell potential, and chemical and electrochemical equilibrium in galvanic cells. *Journal of Chemical Education, 79*(6), 735-738.

Özkaya, A. R., Üce, M., & Şahin, M. (2003). Prospective teachers' conceptual understanding of electrochemistry: Galvanic and electrolytic cells. *University Chemistry Education, 7*(1), 1-12.

Palıcıca,M., Gavrılă, C., & Boacă, V. (2010). Making classes more efficient with interactive methods and techniques, Didactica, 3 (1), [Available online at: http://usabtm.weburl.ro/downloads/Didactica%201(2010).pdf#page=25],Retrieved 20.11.2014.

Perkins, D. (1999). The many faces of constructivism. *Educational leadership, 57*(3), 6-11.

Pesman, H., & Eryilmaz, A. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *The Journal of Educational Research, 103*(3), 208-222.

Rasmussen, C. & Kwon, O. (2007). An inquiry oriented approach to undergraduate mathematics. *Journal of Mathematical Behavior, 26*, 189 – 194.

Rasmussen, C., Zandieh, M., & Wawro, M. (2009). How do you know which way the arrow go? The emergence and brokering of a classroom mathematics practice. In W.-M., Roth (Ed.), *Mathematical representation at the interface of body and culture* (pp. 171-213). Charlotte, NC: IAP - Information Age Publishing.

Regis, A., Albertazzi, P.G., & Roletto, E. (1996). Concept maps in chemistry education. *Journal of Chemical Education, 73*(11), 1084–1088.

Reynolds, A. J., & Walberg, H. J. (1992). A structural model of science achievement and attitude: An extension to high school. J*ournal of Educational Psychology*, *84*(3), 371-382.

Ringnes, V. (1995). Oxidation-reduction learning difficulties and choice of redox models. *School Science Review,77*(279), 477–478.

Rosenthal, D. P., & Sanger, M. J. (2012). Student misinterpretations and misconceptions based on their explanations of two computer animations of varying complexity depicting the same oxidation–reduction reaction. *Chemistry Education Research and Practice, 13*(4), 471-483.

Sanger, M. J., & Greenbowe, T. J. (1997a). Common student misconceptions in electrochemistry: Galvanic, electrolytic, and concentration cells. *Journal of Research in Science Teaching, 34*(4), 377-398.

Sanger, M. J., & Greenbowe, T. J. (1997b). Students' misconceptions in electrochemistry: Current flow in electrolyte solutions and the salt bridge. *Journal of Chemical Education, 74*(7), 819-823.

Sanger, M. J., & Greenbowe, T. J. (1999). An analysis of college chemistry textbooks as sources of misconceptions and errors in electrochemistry. *Journal of Chemical Education, 76*(6), 853-860.

Sanger, M. J., & Greenbowe, T. J. (2000). Addressing student misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *International Journal of Science Education, 22*(5), 521-537.

Schmidt, H. J. (1994). Der Oxidationssbegriff in Wissenschaft und Unterricht [The oxidation concept in science and education]. *Chemie in der Schule, 41*(1), 6-10.

Schmidt, H. J., & Volke, D. (2003). Shift of meaning and students' alternative concepts. *International Journal of Science Education, 25*(11), 1409-1424.

Schmidt, H. J., Marohn, A., & Harrison, A. G. (2007). Factors that prevent learning in electrochemistry. *Journal of research in science teaching, 44*(2), 258-283.

Schroeder, J.D., & Greenbowe, T.J. (2008). Implementing POGIL and the science writing heuristic jointly in undergraduate organic chemistry – student perceptions and performance. *Chemistry Education Research and Practice*, *9*(2), 149-156.

Şeşen, B. A., & Tarhan, L. (2013). Inquiry-based laboratory activities in electrochemistry: High school students' achievements and attitudes. *Research in Science Education, 43*(1), 413-435.

Simonson, S. R., & Shadle, S. E. (2013). Implementing process oriented guided ınquiry learning (POGIL) in undergraduate biomechanics: Lessons learned by a novice. *Journal of STEM Education*, *14*(1), 56-63.

Smith, E. L., Blakeslee, T. D., & Anderson, C. W. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching, 30* (2), 111-126.

Soltis, R., Verlinden, N., Kruger, N., Carroll, A., & Trumbo, T. (2015). Process-oriented guided inquiry learning strategy enhances students' higher level thinking skills in a pharmaceutical sciences course. *American journal of pharmaceutical education, 79*(1), 1-8.

Spencer, J. N. (1999). New directions in teaching chemistry: A philosophical and pedagogical basis. *Journal of Chemical Education, 76*(4), 566-569.

Spencer, J.N. (2000). New directions in general chemistry: How recent research is changing the introductory chemistry course. In W.B. Bond (Ed.), *Teacher's guide: AP chemistry* (pp. 1-9). New York: College Board Publications.

Spencer, J.N. (2006). New approaches to chemistry teaching. *Journal of Chemical Education, 83*, 528-535.

Spencer, J.N., & Moog, R.S. (2008). The process oriented guided inquiry learning approach to teaching physical chemistry. In M.D. Ellison & T.A. *Schoolcraft (Eds.), Advances in teaching physical chemistry: ACS symposium series 973* (pp. 268-279). Washington, D.C.: American Chemical Society.

Stevens, R. J., & Slavin, R. E. (1995). The cooperative elementary school: Effects on students' achievement, attitudes, and social relations. *American Educational Research Journal, 32*(2), 321–351.

Straumanis, A., & Simons, E. A. (2008). A multi-institutional assessment of the use of POGIL in organic chemistry. In R.S. Moog, & J.N. Spencer (Eds.), ACS 173 Symposium Series 994: *Process-oriented guided inquiry learning* (pp. 226–239). Washington, DC: American Chemical Society.

Sumfleth, E., Stachelscheid, K., & Todtenhaupt, S. (1991) Redoxreaktionen in der Sekundarstufe I - Sauerstoffübertragung und/oder Elektronenübertragung? [Redox reactions at secondary level I - oxygen transfer and / or electron transfer?] *Naturwissenschaften im Unterricht – Chemie, 8*, 77.

Taşdelen, U. (2011). *The effects of computer-based interactive conceptual change texts on 11th grade students' understanding of electrochemistry concepts and attitude toward chemistry* (Unpublished doctoral dissertation). Middle East Technical University, Ankara.

Treagust, D. F., Mthembu, Z., & Chandrasegaran, A. L. (2014). Evaluation of the predict-observe-explain instructional strategy to enhance students' understanding of redox reactions. I. Devetak and S. A. Glaz ˇar (eds.), *Learning with understanding in the chemistry classroom* (265-286), DOI: 10.1007/978-94-007-4366-3_14, Springer Science+Business Media B.V.

Vacek, J. J. (2011). Process oriented guided inquiry learning (POGIL), a teaching method from physical sciences, promotes deep student learning in aviation. *Collegiate Aviation Review*, *29*(2), 78–88.

Vanags, T., Pammer, K., & Brinker, J. (2013). Process-oriented guided inquiry learning improves long-term retention of information. *Advances in Physiology Education, 37*(3), 233-241.

Varma-Nelson, P., & Coppola, B. P.. (2005). Team learning. In N. J. Pienta M. M. Cooper T. J.Greenbowe, (Eds.) *Chemists' guide to effective teaching: Volume I* (pp. 155-169). New Jersey: PrenticeHall: Upper Saddle River.

Wozniak, B. M. (2012). *Effect of process-oriented guided-inquiry learning on non-majors' biology students' understanding of biological classification* (Order No. 1517251). Available from ProQuest Dissertations & Theses Global. (1039584600). Retrieved from http://search.proquest.com/docview/1039584600?accountid=11248

Yang, E. M., Andre, T., Greenbowe, T. J., & Tibell, L. (2003). Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education*, *25*(3), 329-349.

Yaqoob, M. (2007). *Developing creative thinking: A cognitive approach to the teaching of English literature*. Doctorate Thesis, National University of Modern Languages, Islamabad.

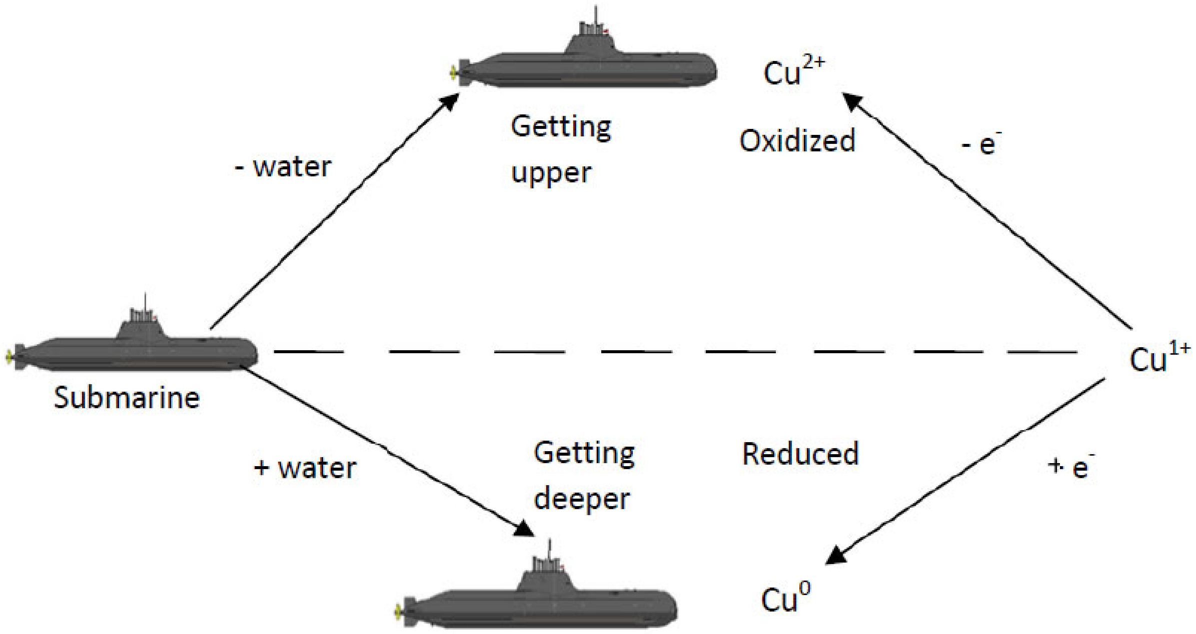
Yılmaz, A., Erdem, E., & Morgil, F. İ. (2002). Students' misconceptions concerning electrochemistry. *Hacettepe University Journal of Education, 23*, 234-242.

Appendix A

Activity 1: An analysis of redox reactions

(How does electron exchange happen during oxidation and reduction?)

Model 1: Oxidation and Reduction

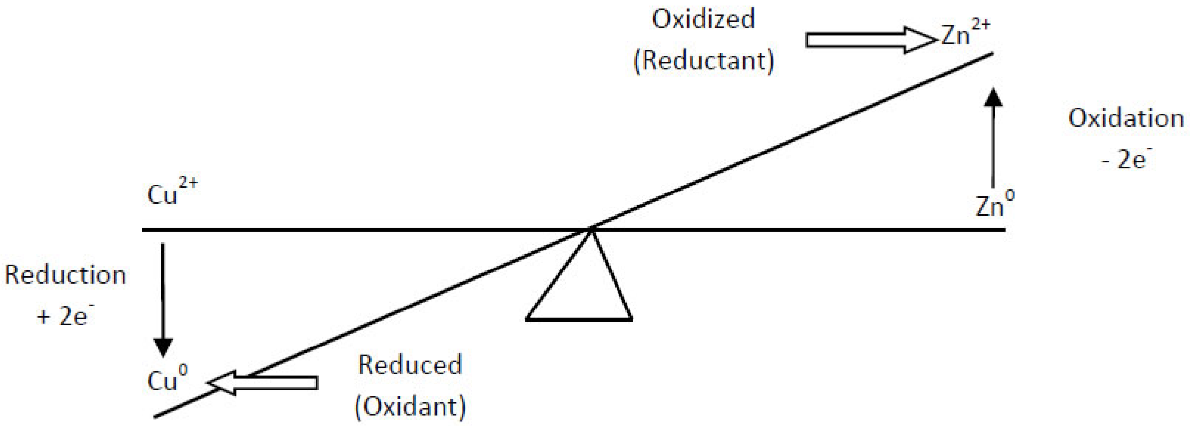


Critical Thinking Questions

1. How did Cu^{1+} change in the direction submarine gives out water?
2. How did Cu^{1+} change in the direction submarine takes in water?
3. In which direction was there an increase in Cu^{1+}?
4. How did oxidation happen in the valence of copper (by releasing electrons or by attracting electrons?)
5. How did reduction happen in the valence of copper (by releasing electrons or by attracting electrons?)

6. Write down the relationship of electrons with oxidation and reduction.

Model 2: Oxidation, Reduction, and Electron Exchange



$+e^-$		$-e^-$
$X^{1+} + 1e^- \text{-------->} X$		$Y \text{-------->} Y^{1+} + 1e^-$
$X^{1+} + 2e^- \text{-------->} X^{1-}$		$Y^{1+} \text{-------->} Y^{2+} + 1e^-$
$X + ne^- \text{-------->} X^{n-}$		$Y \text{-------->} Y^{n+} + ne^-$

Critical Thinking Questions

1. In which element did oxidation happen?

2. In which element did reduction happen?

3. Which is the oxidized element?

4. Which is the reduced element?

5. What do we call the substance oxidizing the element opposite when it attracts electrons?

6. What do we call the substance reducing the element opposite when it releases electrons?

7. Which is oxidant and which is reductant?

8. Study the X and Y reactions in the model, and write down the reaction where the Zn0 element releases 2 electrons.

9. Write down the reaction where Cu^{2+} attracts 2 electrons.

Appendix B

Students' Answers to Question 12 in ECT Post-test

12a) Which is true for Galvanic cells?	Exp. %	Control %	**12b) Which explains the reason for your answer best?**	Exp. %	Control %
***A.** Galvanic cells work spontaneously.	94,64	66,10	*** a)** In galvanic cells, reactions in the two electrodes tend to happen spontaneously and a flow of electrons happens from the anode into the cathode through and external conductor.	78,57	44,07
B. Anode is positively charged because it releases electrons; cathode is negatively charged because it attracts electrons.	0,00	6,78	**b)** The place of anode and cathode is determined by the physical placement of half-cells	7,14	5,08
C. Electrons enter the electrolyte from the cathode, they are carried by electrolyte and salt bridge, and then they complete the circuit and they emerge in the anode.	1,79	3,39	**c)** Anode is always on the left.	8,93	15,25
D. Electrons flow in aqueous solutions without assistance of ions.	1,79	11,86	**d)** Electrons can move in solutions just like ions do.	1,79	5,08
	1,79	6,78		3,57	25,42
The answers that I have given to the two questions above:			**a.** I am sure **b.** I am not sure.		