Science Education International
Vol. 17, No. 4, December 2006, pp. 253- 273

International Council of Associations in Science Education

Cooperative and Context-based Learning on Electrochemical Cells in Lower Secondary Chemistry: A Project of Participatory Action Research

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ABSTRACT *This paper discusses a project of Participatory Action Research (PAR) on lower secondary chemistry education. In this ongoing project, practicing teachers and university researchers in chemical education jointly carry out projects for developing and evaluating new lesson plans. The focus of the PAR group is to develop teaching/learning activities that are student-centred, integrate new media in the classroom, and invest on cooperative learning methods. The present attempt aimed to develop a context-based and cooperative learning approach for teaching electrochemistry to tenth-grade students, and the paper summarizes these activities, and the results from their testing and evaluation. Implications for teaching/learning in lower secondary chemistry are also discussed.*

KEY WORDS: *Cooperative learning, electrochemistry, Participatory Action Research.*

Introduction

Participatory Action Research (PAR) brings together researchers and teachers aiming at jointly developing school curricula and learning about authentic classroom practices (Eilks & Ralle, 2002). A PAR project has been carried out by a group of chemistry teachers and university researchers in chemical education who continue to work together for almost six years (Eilks, 2003). The project's objectives concerning electrochemistry were to develop and evaluate lesson plans for teaching electrochemistry to lower secondary students, by structuring them around everyday and relevant applications, and designing a respective student-oriented learning environment. The paper also reports on a case study that investigated to what extent the principles of context-orientation (starting from an everyday-life issue to study science content) and the techniques of cooperative learning can be successfully applied in teaching electrochemistry at lower secondary chemistry lessons.

The idea of developing a lesson plan on the subject of electrochemistry was based on two starting points. The first relates to the fact that in most cases in German lower secondary chemistry education, redox reactions are almost exclusively introduced through the use of historical galvanic cells (e.g., the Daniell voltaic cell) for describing electron transfer and electrochemical cells. Modern voltaic cells, such as the alkali-manganese voltaic cell, that are used in everyday life are considered by most teachers to be too difficult for lower secondary students. Working with these modern voltaic cells is mainly postponed until upper secondary chemistry courses. Unfortunately, only a small percentage of students continue studying chemistry at this level in Germany (Fischer, Klemm, Leutner, Sumfleth, Tiemann, & Wirth, 2003). Thus, a lot of German students are never confronted with learning about these current and highly-relevant applications of electrochemistry.

The second starting point relates to the difficulty of teaching electrochemistry in lower secondary chemistry lessons (Davies, 1991; Finlay, Stewart, & Yarroch, 1982; Butts & Smith, 1987) and the fact that chemistry teaching in Germany has been repeatedly characterized as "teacher-centred," especially for difficult concepts and principles, like electrochemistry (Fischer, Klemm, Leutner, Sumfleth, Tiemann, & Wirth, 2003).

Understanding Redox Reactions and Electrochemical Cells

Understanding redox reactions is a difficult task. In German chemistry education, difficulties often arise, because alternative conceptions are used in different phases of the curriculum (Schmidt, 1997). Oxidation and reduction are usually introduced in chemistry classes at a phenomenological level using Lavoisier's theory that is based on reactions with oxygen or on the release of oxygen. Later, oxidation and reduction are completely reintroduced as electron-based reactions. Students often are not able to clearly understand this shift (Schmidt, 1997), and tend to classify reactions based on a mix of criteria or by even developing completely different criteria (Garnett & Treagust, 1992b). This problem continues throughout upper secondary chemistry classes, where students are not always able to differentiate clearly between the two alternative explanations, that is, the Lavoisier model of oxidation, and the electron-transfer model (Valanides, Nicolaidou & Eilks, 2003). A second problem relates to the relatedness of oxidation and reduction. In Lavoisier's theory, oxidation and reduction are completely different processes that can appear independently from one another. Lavoisier defined oxidation as a combination with oxygen and reduction as a reaction with a release of oxygen. The electron-transfer theory considers both reactions themselves as complete redox reactions. Garnett and Treagust (1992b) reported that students often tend to describe oxidations and reductions as independent processes, even after the electron-based theory has been introduced. In the field of electrochemistry, only the concept of electron transfer can acceptably explain that oxidation and reduction are always coupled to each other and can provide a sustained understanding of electrochemical cells.

Concerning electrochemical cells, three major problems have already been identified by teachers and research, namely; (1) understanding electricity and conductivity; (2) correctly conceptualizing the processes within the electrochemical cell; and (3) naming the components of an electrochemical cell (anode and cathode) (de Jong & Treagust, 2002). Garnett and Treagust (1992a) reported that, in order to understand electrical conductivity, students often tend to explain the phenomenon of conductivity through the mobility of electrons. This misconception concerning the conductivity of electrolytes is often related to the previously-learned concept of electrical conductivity in metals. The concept of conductivity in metals, as a movement of electrons, is normally introduced to the students earlier and is usually over-generalized by students (Garnett & Treagust, 1992a). Thus, students tend to explain the electrical conductivity in electrolytes either as a flow of free electrons within the electrolyte (Sanger & Greenbowe, 1997a, 1997b; Ogude & Bradley, 1994, 1996) or as a transport of electrons with the help of ions (Garnett & Treagust, 1992a).

However, it is not only the concept of electrical flow that is misunderstood at the particle level. The term "energy consumption" is often used in students' everyday life, and they tend to think of energy as a substance, which is "used up" at the end of a reaction (de Posada, 1997). The students interpret energy as electrons, which also "disappear," because they are used up by an electrical device. With this interpretation, there is no need for a closed electric circuit, i.e., a connection from the consumer back the power supply, or the salt bridge within voltaic cell. Another problem occurs from misusing the words anode, cathode, positive pole and negative pole. The interpretations of charges within the electrodes caused by electrochemical reactions become students' criteria for characterizing cathodes and anodes (Sanger & Greenbowe, 1997a; Ogude & Bradley, 1994, 1996), and the terms anode and cathode are conceptualized as synonyms for positive pole or negative pole, although the relations are different when using a voltaic cell or discussing electrolysis processes (Garnett & Treagust, 1992a). Even by accepting the polarization occurring within the electrochemical cell, students sometimes fail to correctly understand both the connection between the oxidation potential of the elements involved and the usefulness of the direction of polarization for identifying the oxidized and reduced substances (Garnett & Treagust, 1992a; Sanger & Greenbowe, 1997a, 1997b; Ogude & Bradley, 1994, 1996).

Thus, it seems necessary to strongly emphasize a good explanation of the closed electric circuit, its necessary components, and the way electricity is conducted within the inner and outer electric circuits. This is directly related to the principles of conservation of charge, conservation of atoms, and conservation of mass. It is also important to clearly identify the charges of the electrodes based on oxidation and reduction, especially when naming the positive and negative pole, while talking about a voltaic cell or the process of electrolysis in charging a storage voltaic cell, respectively.

Background and Research Questions

The present action research group existed prior to undertaking this project for about four years (Eilks, 2003). It includes university researchers in chemistry education and about 15 teachers from different grammar, middle, and comprehensive schools in western Germany. This PAR group usually meets every four weeks for a whole afternoon. During these meetings, lesson plans are developed and teachers' feedback from their classroom experiences is discussed. In the past, the group developed various lesson plans dealing with the particulate nature of matter in introductory chemistry teaching (Eilks, Moellering, & Ralle,

2004) and for applying more open and cooperative methods in chemistry teaching (Eilks, 2005). The group was originally guided by researchers from the University of Dortmund, who are now affiliated with the University of Bremen, Germany.

This specific group attempted to improve the teaching-learning process related to electrochemistry taking into consideration that:

- Introducing redox reactions based on electron-transfer and connecting this concept to electrochemical cells is a commonly stated goal for lower secondary chemistry education (tenth grade, age range 15-16, which is the last year of compulsory chemistry education in Germany) in nearly all governmental syllabi existing in the 16 German States, even though each State has a different official curriculum.
- The introduction of redox reactions in the syllabi is always linked to the use of voltaic cells. Another key focus is to divide the overall redox reactions into their oxidation and reduction halves, and then handle the respective half-reaction equations for both parts. Some syllabi also state goals that target the development of skills dealing with technical issues, or problems related to disposing and recycling batteries.

In most cases, electrochemistry is almost exclusively introduced by discussing historically-important cells, like the Daniell voltaic cell, while context-based approaches are rarely applied. For example, a discussion of the alkali manganese battery, zinc air battery, or the lead acid accumulator, is considered by most teachers to be rather difficult for lower secondary chemistry students. Thus, current applications of electrochemistry are not elaborated upon, until upper secondary chemistry lessons. Unfortunately, only half of the students in Germany enter upper secondary education, and only few of them attend chemistry courses. The main questions of the present attempt were the following:

- Is it possible to successfully design a lesson plan using meaningful contexts from everyday life, for teaching electrochemistry in lower secondary science lessons, so that students will successfully learn the redox concept as a concept of electron transfer, and organize learning in this lesson plan in a completely student-centred way by using a combination of different methods of cooperative learning?
- To what extent can the principles of context-orientation and cooperative learning orientation be applied successfully to the framework of such a difficult topic in lower secondary chemistry education?

Method

The underlying structure of the project was based on Participatory Action Research (Eilks & Ralle, 2002; Eilks, 2003) This approach tries:

- to build a systemic bridge between authentic classroom practice and university chemistry education research in projects of curriculum innovation.
- to make use of teacher experiences by systematically drawing upon them in the processes of curriculum development and evaluation.
- to transform empirical research results about learning and instruction into lesson plans and teaching materials in a systemic fashion.

- to make the whole process an intensive in-service teacher training practice.
- to evaluate teaching practices and the process of curriculum innovation to gather empirically-based knowledge about the teaching/learning process in authentic classroom environments.

The whole process is based on close cooperation between university researchers and classroom practitioners. Both groups are equally important, but have different roles (Eilks & Ralle, 2002; Eilks, 2003). Teachers and researchers together collaboratively try to develop new teaching methods, materials, and lesson plans that can support their own practices and those of other practitioners as well. The teachers' role connects practical teaching experiences with the process of curriculum development. This process is also supported by chemistry education researchers, who are more familiar with new ideas from chemistry education and relevant empirical research in the field.

Development starts with discussing related empirical research evidence with teachers, in an attempt to investigate to what extent research findings can guide and support their work. A provisional lesson plan is then discussed within the PAR group until all members consider that it is useful for bridging the gap between intended learning outcomes and actual student learning.

Then, teaching materials for implementing the lesson plan are jointly designed and developed. The lesson plan is later pilot-tested in single classrooms by individual teachers. The entire PAR group discusses and reflects upon both the approach and the practical classroom experiences. The lesson plan is continuously revised, until the group is satisfied with the actual learning practice and its outcomes. In the next phase, the lesson plan and the accompanying materials are further tested by involving more classes. Additional data is collected through student questionnaires and interviews, or by using group discussions among the participating teachers and researchers. The process targets the development of better lesson plans and teaching materials, by following and evaluating every step of this cyclical process (Eilks & Ralle, 2002).

In the present project, five teachers from five different grammar schools (German Gymnasium) and a total of nine classes were involved. The testing of the specific lesson plan for electrochemistry was repeated in three separate cycles. The first cycle of testing was done in parallel with the development. The second cycle took place few months later, and the third cycle a year later. Table 1 shows an overview of the project.

Teachers Influence on the Structure of the Lesson Plan

One of the central ideas of cooperative curriculum development relates to using teachers' ideas and teaching experiences for restructuring the curriculum. Each new lesson plan and each new idea for teaching materials are intensively negotiated within the action research group. These negotiations usually guide the modification of the initial ideas prior to testing them in the classroom. It is expected that this process can result in more effective lesson plans and materials, because the process integrates teachers' ideas and follows a repeated testing of the lesson plan and the relevant materials (Eilks, 2003). Additionally, the discussions within the group create a sense of ownership of the materials by the teachers involved in. As an example of teachers' influence on the overall process and their

Table 1
Development of the Lesson Plan

Schedule	Development
July to August 2003	Analysis of relevant literature Collecting ideas for methods and experiments First draft of the whole lesson plan
Mid September 2003 (First meeting of the group)	Presentation and discussion of the draft lesson plan within the PAR group Collecting ideas for restructuring the lesson plan
September to October 2003 (Revision of the lesson plan)	Revising the draft of the first half of the lesson plan on simple voltaic cells based on teachers' comments Collecting ideas for revising the part of the lesson plan about storage voltaic cells, which was considered by the teachers to be too difficulty for the students
Mid October 2003 (Second meeting of the group)	Final negotiation of the part of the lesson plan on simple voltaic cells within the group and discussion of ideas for new teaching approaches for the part of the lesson plan about storage voltaic cells
October to November 2003 (Final revision of the lesson plan and start of the first cycle of testing)	Revision of the second part of the lesson plan about storage voltaic cells Testing of the first half of the lesson plan by two teachers Observation of the lessons by one of the university researchers and reflection by the teachers after each lesson
Mid November 2003 (Third meeting of the group)	Reflection on first classroom experiences Negotiating the last tasks of the lesson plan
November to December 2003 (Last changes and finishing the first cycle of testing)	Testing of the second half of the lesson plan by two teachers Observing the lessons by one of the university researchers and reflection by the teachers after each lesson Test and student questionnaires
Mid January 2004 (Fourth meeting of the group)	Reflection by the whole group
January to April 2004 (Second cycle of testing)	Testing in another 3 classes
October to December 2004 (Third cycle of testing)	Testing in another 3 classes

feelings of ownership, two small episodes from the meetings of the action research group are presented.

(1) The initial draft of the chemistry lesson plan was structured as a classical jigsaw classroom (Aronson, Stephens, Sikes, & Blaney, 1978) and included teaching about different batteries and storage cells. The initial idea was a jigsaw classroom covering the alkali-manganese voltaic cell, zinc air voltaic cell, hydrogen fuel cell, lead storage battery, lithium ion storage battery, and nickel metal hydride storage battery, as tasks for the expert groups' work within the jigsaw schedule. In the first meeting, the teachers suggested that the inclusion of three simple batteries

and three storage batteries into one jigsaw classroom was a very demanding task. Thus, they alternatively divided the jigsaw classroom into two separate jigsaw classroom settings. The first jigsaw classroom setting dealt, in three different expert groups, with the hydrogen fuel cell, the alkali manganese battery, and the zinc air battery. In the second jigsaw classroom setting, the teachers planned to ask the student groups to deal with information from the Internet about three different storage batteries (lead/lead oxide, nickel metal hydride, and lithium ion technology).

In the second meeting of the PAR group, as indicated in Table 1, the teachers conducted an Internet search using various Internet search engines. Teachers tried to identify potentially useful web-sites related to storage batteries, and tried to categorize the existing web information. The teachers were not successful, because they did not identify any web resources available in German language, which could be considered appropriate for students. Thus, they decided to skip the second jigsaw setting on the storage voltaic cells, as it was previously described. The teachers decided to restrict the search for storage voltaic cells exclusively to only the lead acid storage voltaic cell. For lead acid storage voltaic cell, a few websites were available that were considered more or less appropriate with some additional help. Some teachers suggested structuring this phase along Internet websites based on the method of a group work, where all the student groups work parallel on the same tasks. Others reported negative experiences with this kind of parallel group work using the Internet, and resisted the idea. From their perspective, parallel group work does not support cooperative learning. Only few students usually work, and no overall group cooperation takes place.

With an input from the university researchers, a new lesson plan was adopted by including parallel group work via the Student Teams and Achievement Divisions Method (STAD) (Slavin, 1984). The STAD method is a system of using a pre- and post-test, where the students, prior to the post-test and after the pre-test, are asked to train each other in small heterogeneous learning groups. The aim is to ask high achievers to work with low achievers in an attempt to increase the overall understanding and knowledge of the group. None of the teachers had previously even heard about this method, but, after presenting its main ideas, the approach was unanimously accepted.

By taking the idea of the STAD, an additional idea was included. The teachers had learned about the method of a learning card index in another project conducted by the same PAR group, and were more than happy to apply this method again. A learning card index is a set of cards covering questions on the front side and their solution on the back. Such a tool allows to individually control one's own knowledge or to play games related to the respective subject matter within small groups.

(2) Within the PAR group, it was agreed that all student tasks within the different expert groups in the initial jigsaw classroom should be based on a common theoretical text. This text was extensively pre-structured by one of the researchers (S.M.) using empirical research evidence. It was then intensively discussed in the first and the second group meetings, and the PAR group selected a modified version of the text after consulting additional sources of information. A help station at the teachers' desk was also included, as suggested by one of the

teachers. At this help station, the teacher offered additional help by presenting an experiment based on the Daniell voltaic cell. Explanations were offered orally and in a pictorial form, as presented in Figure 1.

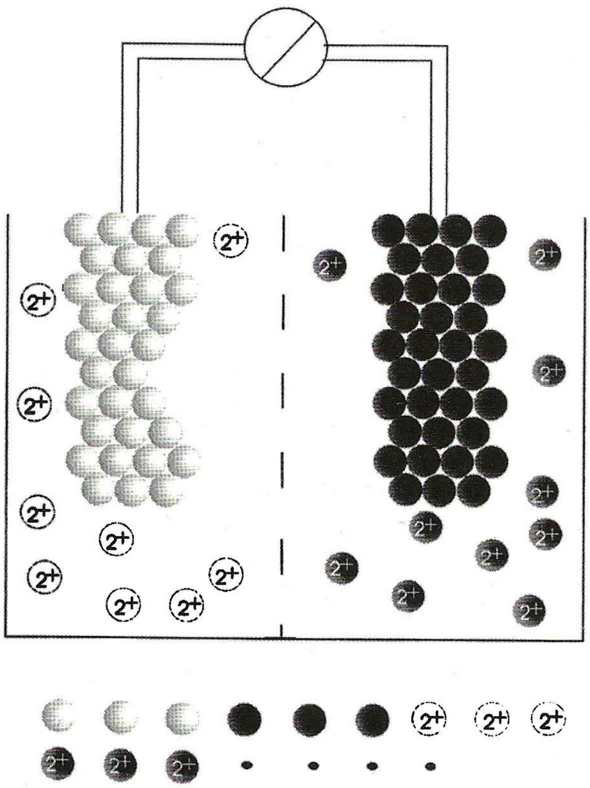


Figure 1. Explaining the Daniell Voltaic Cell. The Pictorials at the Bottom Can Be Cut Out and Used to Illustrate the Dynamic Process by Moving Them on the Figure

This idea stemmed from teacher experiences with "expert stations" from the "Learning at Stations" method (Eilks, 2002), where the present PAR group worked on a related project for two years prior to the electrochemistry project. This approach was evaluated by the teachers who unanimously concluded that it could facilitate students' learning.

From the beginning of testing, the teachers requested to use a multimedia visual aid of the Daniell voltaic cell (Sanger & Greenbowe, 1997a). Thus, an animation was then developed by an external partner. The external partner's suggestions were continuously analysed and evaluated by the teachers via email exchanges. An intense discussion on the use of computer animations took place within the PAR group, and, finally, a completely revised version of the visual aid was adopted. This multimedia animation is presented in Figure 2 and replaced, in the third cycle of testing (as indicated in Table 1) the pictorial aid in Figure 1.

(www.ifdn.tu-bs.de/chemiedidaktik/material/material_computer/quelldaten/animationen/elektrochemie/-daniell_element/daniell.html)

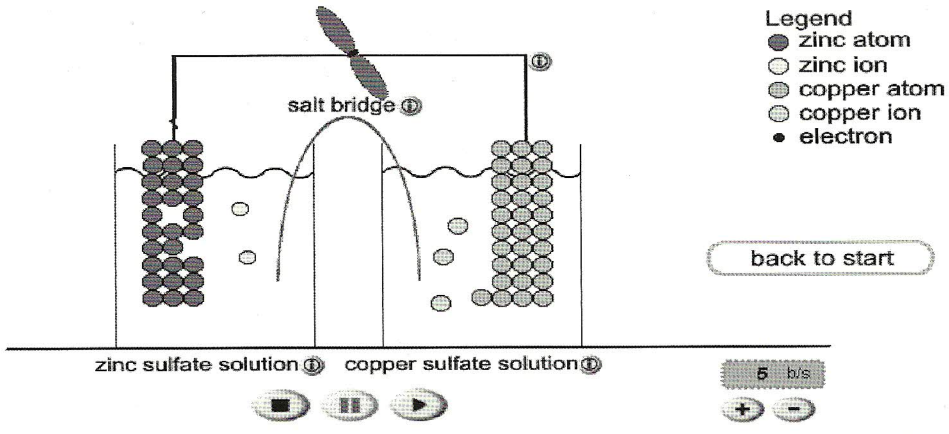


Figure 2. Screenshot of a Multimedia-Animation of the Daniell Voltaic Cell

The Lesson Plan

The lesson plan was developed for tenth-grade students (age range 15-16) at German lower secondary chemistry education. It consists of four phases:

- A safeguarded jigsaw classroom with doubled expert groups (Eilks & Leerhoff, 2001) on the hydrogen fuel cell, alkali manganese battery, and zinc air battery.
- Parallel group work using the Internet to study the lead acid accumulator.
- A phase of cooperative training in small groups using a learning card index.
- A cooperative test that was individually answered, but it was taken into account for a competition among the students' groups, where the sum of the individual scores of the members of each group was calculated, as described in the Student Teams and Achievement Divisions (STAD) Method (Slavin, 1978).

Table 2 gives an overview of the lesson plan.

Table 2
The Lesson Plan

Period (45 min. each)	**Frame**	**Method/Content**	
1		Textual approach	Setting up questions
2-5	*Working in the same groups (except jigsaw expert groups) to compete in a group competition (STAD)*	*Jigsaw classroom*	Hydrogen fuel cell, alkali manganese battery, zinc air battery
6-7		*Parallel work in groups (Internet)*	Lead acid accumulator
8-9		*Cooperative training (learning card index)*	All topics
10		*Test*	All topics

Setting Up Questions

To allow a context-driven textual approach, the lesson plan starts with a text sampled from the website of GRS Batterien (**G**emeinsames **R**ücknahme**s**ystem fuer Batterien, or Comprehensive Battery Reclamation System), which is a joint effort of all battery producers. The obligation of GRS Batterien to collect all empty batteries and take the responsibility for recycling or disposing them in an environmentally-friendly fashion is dictated by law.

The text deals with the use of different batteries and accumulators. It mentions the most widely-used batteries and accumulators, which became the main topics in the subsequent classroom periods: the zinc oxygen battery, hydrogen fuel cell, alkali manganese cell, lead acid accumulator, lithium ion accumulator, and nickel hydride accumulator. Environmental problems, technical properties, and aspects of recycling were also mentioned. Students' ideas and questions were collected and form the basic frame of the lesson plan. The questions were repeatedly evaluated in subsequent class sessions, as to whether they have been satisfactorily answered and explained, or whether additional work was needed.

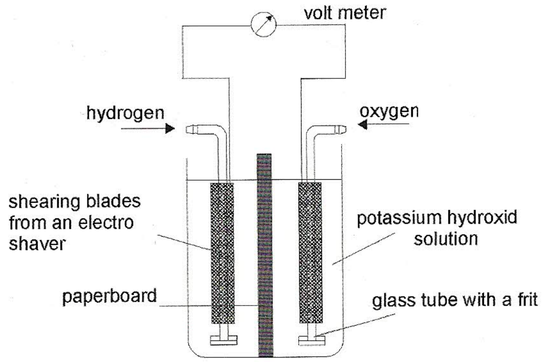
After completing the contention, the students were divided into groups of 6 students to complete the rest of the lesson plan (except the unit of expert group work in the jigsaw classroom). The groups were heterogeneous in themselves, whereas the overall abilities of the groups were comparable. The students in each group were responsible for each other. They knew that they would be individually tested, and results within each group would be also taken into account for the group's final grade. In practice, the teacher was able to use the group scores and the individual scores for grading his/her students. In some of the German States, there are restrictions in using group scores to decide the final scores for individual students, but most teachers from the Action Research Group agreed to use both grades in a more or less equal weight.

Electrochemical Cells in an Experimental Jigsaw Classroom

Within the second setting, the students work on three important battery systems (hydrogen fuel cell, zinc oxygen cell, alkali manganese cell) in a safeguarded jigsaw classroom as described by Eilks and Leerhoff (2001), and Eilks (2005). The major modification to the original jigsaw classroom was to double the expert groups' work. Every sub-topic was carried out twice, which resulted in two expert groups working on the same sub-topic. This ensured that each subsequent learning group had two experts for each sub-topic, who completed their research independently of one another. A member from each of the initial groups was sent into each of the two expert groups.

The three assigned subtopics were worked out using a parallel approach. The work was structured by a worksheet covering different questions on the topic and through an introduction to the overall experiment, as indicated in Figures 3, 4, and 5. The batteries were constructed in an experiment and their function was evaluated. These tasks forced the students to work out the chemical principles involved and to describe the basic reactions.

A beaker is divided into two cells with cardboard. Two old razor blades from a conventional electroshaver are connected to a fritted glass tube by an adhesive strip. The two glass tubes are affixed to the two half-cells in the beaker, which is filled with potassium hydroxide solution. The razor blades are connected to a voltmeter by cables. Oxygen and hydrogen are introduced into the system. An electric voltage of 650mV can be measured.



The razor blades are used because their surface contains a layer of nickel. In technical fuel cells, platinum is used in most cases. Nevertheless, the experiment allows enough parallels to demonstrate the correct principle.

Figure 3. Constructing a Hydrogen-fuel Cell

A beaker is divided into two cells by cardboard. A zinc electrode and a carbon electrode are put into the two cells. Both electrodes are connected to a voltmeter or a small electric motor.

Sodium hydroxide solution is added to the beaker. After the motor stops the graphite electrode is taken out of the beaker, then put again into the cell after a short time lapse. The motor starts again.

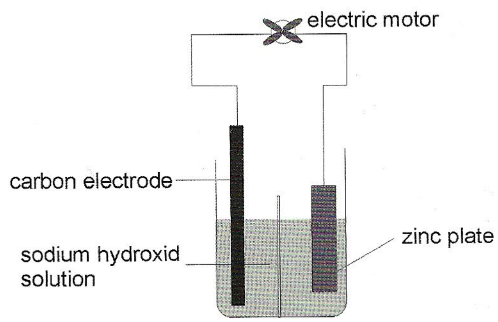


Figure 4. Constructing a Zinc-air Voltaic Cell

Manganese dioxide, ammonium chloride, starch and water are mixed to form a stiff paste. A zinc electrode is wrapped in a sheet of filter paper.

The zinc electrode and a graphite electrode are placed into the mixture. Both electrodes are connected to a voltmeter or a small electric motor.

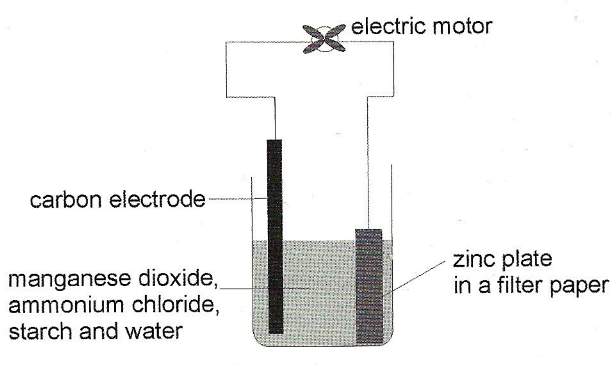
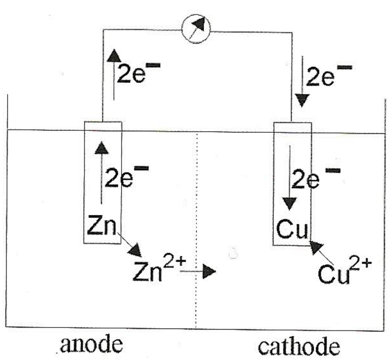


Figure 5. Constructing an Alkali -manganese Voltaic Cell

Additionally, basic concepts and notions about redox reactions were worked out and collected in a glossary. Each expert group received the same text concerning the basics of redox reactions and electrochemical cells. The text offered theoretical explanations of redox reactions and conductivity, and it was illustrated using examples explaining the Daniell voltaic cell. Special emphasis was put on the principles of the conservation of mass, the coupling of oxidation and reduction, and the necessity of recognizing the need for a closed electric circuit.

The students were asked to set up reaction equations for the electrode processes. Different learning aids were available at the teacher's desk and could be explained upon request. This was especially important for understanding the cathode equation of the alkali manganese cell, whose equation is very difficult to visualize. In this case, the help was more structured and the explanation was chosen to start with the reduction of Mn^{4+} to Mn^{3+}.

Finally, the worksheet presented sketches of the voltaic cells, as indicated in Figure 6. This way of sketching electrochemical cells was suggested to the students by the study materials in order to complete the battery principles. At the end, some additional information about economical, technical, and environmental issues had to be gathered from other text sources.



$$Zn \rightarrow Zn^{2+} + 2e^- \; \vdots \; Cu^{2+} + 2e^- \rightarrow Cu$$
$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$

Figure 6. Sketch of the Daniell Voltaic Cell

After the expert groups' work was completed, the students went back to their initial groups and taught each other. After reporting on their expert groups' activities, their main task was to fill out a table in which the different aspects of the various batteries were listed and compared. This included the set-up, function, necessary reaction equations, and the (dis)advantages of each battery. Each battery should be sketched by the whole group as shown in Figure 6. This work could be checked by the students themselves, by comparing their tables and sketches with example solutions.

The Lead Acid Accumulator in Parallel Group Work

The decision to work with the lead acid accumulator in the Internet was chosen, because it was inappropriate to allow students to experiment with lead and lead compounds due to safety reasons. The work was done in parallel groups and structured through a worksheet, which offered different tasks and a selection of web pages to choose from. When possible, each group could use two or three computers, allowing them to work in groups of up to three. The students were asked to check the websites, and to evaluate the set-up and the basic function of the lead acid accumulator. The students were also asked to evaluate the reaction equations (charging and discharging) for the cell.

New ideas and notions were introduced during this phase, such as, electrolysis, accumulator, or charging. The glossary from the jigsaw classroom was thus completed. Finally, the students were required to find information relating to at least one different type of accumulator cell. For these additional assignments, reaction equations were too difficult in most cases and were not required. Once again, example solutions were available upon request at the teacher's desk to allow for self-assessment.

Training by a Learning Card Index and the STAD-test

In the final working phase of the project, the students were asked to prepare themselves in their respective groups for a test, which was administered using the STAD method (Slavin, 1978). A learning card index on the topic was offered to them as a learning aid. The learning card index was a specially-prepared set of flashcards, which had a chemical principle or a question printed on the front side, and the explanation on the back. The card index covered all the important concepts in the lesson plan. Additional cards could be prepared by the students.

Training and self-assessment using the learning card index did not follow any given scheme; the groups were free to find their own learning path. Many different learning strategies could be applied. The original idea was based on asking oneself or another person a question from a card. The cards, which had content already been studied and understood, were put in a second pile, while cards with unknown content remained in the first pile. After a while (a day or two), the second pile was reviewed again. Known cards went into a third pile, but unknown ones came back in the first one. In the event that all cards entered a fourth or fifth pile, the probability was very high that the content had been learned sustainably and had found its way into long-term memory.

While working this way, the groups were aware that it was very worthwhile for better students to tutor those who did not master the materials. Only in the case that the lower achievers were able to achieve a good score on the test, the whole group would have a chance to be the highest-scoring group of all. This strategy was clear to the students, especially to the higher achievers, and was considered as having high potential for fostering group study activities (Slavin, 1978).

At the end, all students took an individual test. The group's score was calculated by adding up the results of all the individual members of the group. The original idea (Slavin, 1978) not to take the absolute scores at the end, but rather to use the difference between the initial scores and the final scores did not make any sense in the present case. Any student's pre-knowledge was not high enough to make a difference in a lesson plan, where a completely new concept is introduced. Thus, only the final scores were used to calculate the group competition results. If the groups were not of the same size, the average score was used. The lesson plan ended with a reflection on the initial questions.

Experiences and Results from the Evaluation

The whole lesson plan was tested and evaluated using the framework of PAR (Eilks & Ralle, 2002). The study took place in three testing rounds, each of them with three learning groups from different grammar schools from western Germany. The first cycle of testing accompanied the last steps of structuring the lesson plan. The second cycle took place three months later and the third cycle took place 12 months later (Table 1). Nevertheless, all groups were taught using nearly the same lesson plan and working materials. Altogether, 232 students were taught using this method.

The first three groups were continuously monitored by one of the university researchers (S. M.). After each lesson, a reflection period was held with the teacher and documented with a narrative report. The group's experiences were regularly discussed within the PAR group. All nine groups did a cognitive test with a maximum score of 25 points covering relevant knowledge from the lesson plan.

Additional data came from two written student questionnaires, which asked for the students' experiences and criticisms. A combination of an open-ended and a Likert-type questionnaire was used. The students were first asked in an open-ended questionnaire to evaluate either the positive or the negative aspects of the lesson plan that they considered important. After the open-ended questionnaire, a Likert-type questionnaire was administered to the students in order to gather information on those points considered important by the teachers and researchers. The questionnaires were similar to those used in Leerhoff and Eilks (2003), Witteck, Most, Leerhoff, and Eilks (2004) and Eilks (2005).

Observations from the Classroom and Teachers' Reflection

All classes within the first cycle of testing, as indicated in Table 1, were observed by one of the accompanying university researchers (S.M.). The observer rated both the feasibility of the concept and students' motivation as very high. Activity and autonomy of learning were mentioned as very positive. It appeared that connecting cooperative learning with laboratory activities was more attractive and motivating for students. The teachers compared the lessons with their previous experiences, and agreed with this conclusion. The students autonomously divided the work within the group and tried to act as a group with mutual support for all members. Most groups were able to conduct the experimental tasks completely without outside help. University observers and teachers described a positive working climate in all groups involved.

The teachers described their learning groups as being previously untrained in autonomous and cooperative learning techniques. Therefore, the teachers were largely surprised by the degree of autonomous on-task activity and competence, which were much higher than what was expected by the teachers. The teachers attributed this to the clarity of the objectives of the project and the cooperative climate among the working groups. The inclusion of the STAD method induced the students to explain their experiments to every member of their group. The teachers expressed the idea that this method increased students' motivation for learning.

Competition among the groups changed student previous practices in labwork.

In conventional group labwork, most of the students were characterized as quite passive. Some students were observed turning themselves into leaders within their group, conducting the experiments and dominating lab activity, but this was no longer considered to be the case within this framework.

The teachers anticipated setting up the reaction equations to be quite difficult. And indeed, some difficulties occurred, especially for those electrochemical cells where a follow-up reaction had to be worked out on the cathode (i. e., understanding the reaction from O_2 to O^{2-} to OH^-). Nevertheless, nearly all groups were able to deal with the textual aids that were given with the materials. The textual aids allowed at least one or two students from each group to find the necessary steps for an explanation. In some groups, an iterative process of refining the reaction equations among several members was observed.

Dealing with the lead acid accumulator seemed to be more difficult. Some problems stemmed from difficulties using the computer room in one school, but others came from evaluating the information from Internet resources. The teachers were not satisfied with this phase of the lesson plan. Although the entire action research group spent one of their meetings searching the Internet for appropriate websites, their use in the classroom was considered to be unsuitable for students learning about the theory of the lead acid accumulator. The teachers asked for a revision using the foundation of a self-structured multimedia-learning environment. A subsequent animation was prepared for the third cycle of testing, and it was used in combination with the different websites. From the teachers' perspective, this created a better learning environment and a more positive atmosphere.

The end phase of training with the learning card index was found to be extremely positive. Only two of the teachers (but none of the students) had ever had any experience with learning card indexes in the classroom. No strategy for using the card index was suggested by the teachers, but the students developed completely different strategies by themselves. Some groups simply copied the cards into their folders, some asked each other about the cards within a game, and some worked individually in the fashion of the original learning card index method (looking at the questions, answering, controlling, and sorting the cards in terms of their perceived need for repetition).

Overall, the teachers themselves maintained a very high level of activities, especially in the jigsaw classroom and during the card index phase. The teachers were happy to change their style of teaching in this way and reported a lot of unexpected outcomes, which were primarily attributed to working with the learning card index. Previous experiences with the jigsaw classroom method from former projects of the action research group were confirmed (e.g., Eilks, 2005).

Results of the Written Test

The written test contained a total of 10 questions. It was prepared prior to the classroom teaching and was negotiated within the action research group. The test was considered as being very demanding, when compared to the teachers' expectations and to experiences from teaching the same topic using other teaching approaches. The 10 questions covered all of the central concepts of electrochemistry (e.g., oxidation, reduction, the electrochemical cell, the accumulator cell, electrolysis, etc.). Some questions addressed the set-up of the various cells and the principles explaining their operation, including their respective reaction equations. In one of the questions probing all aspects of an electrochemical cell, the students were allowed to answer using a cell of their choice. Finally, some of the questions dealt with aspects of practical applications and environmental issues. The test was given a maximum score of 25 points. A total of 222 students, out of the 232, participated in the test.

The test results within the various learning groups differed. This was expected, because the teachers evaluated at the outset the groups as being "excellent," "average," and "not so good". Nevertheless, 213 of the 222 students completed the test successfully by achieving more than 50% of the total points, which in most German lower secondary schools is commonly accepted as the benchmark for successfully passing an exam. The average score of all students was 76.3 %. Many of the students achieved the level of 'good' and 'very good' results (104 students among the 222 were above 80%). The final results were considered to be unexpectedly high, as indicated in Figure 7.

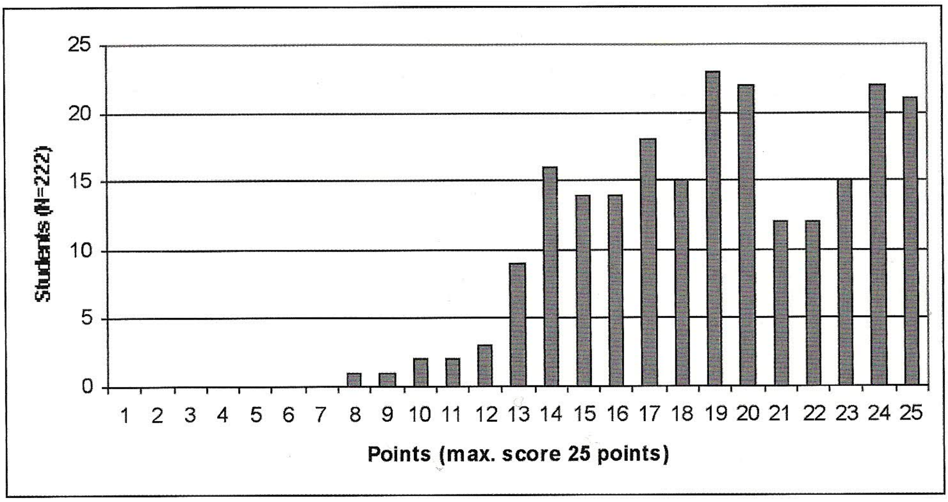


Figure 7. Results from the Written Test from Nine Learning Groups (N = 222)

Students' Viewpoint

In the open questionnaire at the end, the participating students were asked about the major differences they perceived between this lesson plan and their conventional chemistry lessons. The answers were evaluated as to whether they gave information about students' overall considerations or about single aspects of the teaching strategies. Based on the students' answers, different categories were formed and evaluated. These categories covered students' ideas concerning autonomous learning, cooperation, communication, learning with the Internet, learning with the card index, and learning using the textual approach. The categories related to either positive or negative comments. Table 3 summarizes the categories of the students' answers from the open questionnaire concerning the teaching methods. Most of them characterised the lesson plan as being more attractive than any other normal lesson plan, and referred to differences in the autonomy of learning and to the possibilities for cooperation. Concerning the context-based approach of the lesson plan, only 19 students mentioned aspects of content and textual approach in their replies, and 14 of them characterised the shift towards more contextualized approach as the main positive aspect in comparison with conventional lesson plans.

Table 3
Aspects Mentioned by the Students in the Open Questionnaire (N=232)

	Number of Students
Overall considerations mentioned	
... in a positive sense.	87
... in a negative sense, because of demands that were too high.	5
... in a negative sense, because the student did not like it.	2
... in a negative sense, without mentioning any reason.	18
Aspects of autonomous learning mentioned	
... in a positive sense.	52
... in a negative sense, because of demands that were too high.	2
... in a negative sense, because the student did not like it.	0
... in a negative sense, without mentioning any reason.	0
Aspects of cooperation mentioned	
... in a positive sense.	71
... in a negative sense because of demands that were too high.	9
... in a negative sense, because the student did not like it.	2
... in a negative sense without mentioning any reason.	14
Aspects of communication mentioned	
... in a positive sense.	34
... in a negative sense because of demands that were too high.	7
... in a negative sense, because the student did not like it.	1
... in a negative sense without mentioning any reason.	5
Learning on the internet mentioned	
... in a positive sense.	17
... in a negative sense because of demands that were too high.	2
... in a negative sense, because the student did not like it.	0
... in a negative sense without mentioning any reason.	5
Working with the learning card index mentioned	
... in a positive sense.	36
... in a negative sense because of demands that were too high.	0
... in a negative sense, because the student did not like it.	0
... in a negative sense without mentioning any reason.	3

Some indicative examples of responses from the questionnaire were as follows:

We were able to work more autonomously. Everyone was important. Not only the high achievers were asked to contribute.

It was better that we got to work together with our classmates. It was less boring when compared with other lessons. It was necessary and good to be responsible for following the teaching all the time. Nevertheless, it was easier!

We were able to learn from each other. In case of problems, it was possible to repeat things together with others.

I liked the lessons using the computer. I also liked the fact that we learned face-to-face from each other. This was better than hearing everything from the teacher.

I liked the learning card index most. By using the card index, we learned faster and more effectively, when compared with conventional repetitious learning.

The choice of the topic for a lesson plan like this was good. It was very interesting and a lot of questions from everyday life were answered.

The Likert-type questionnaire presents a similar picture. The students' responses were very positive. Nearly 90% of all students agreed or partially agreed that teaching became more attractive and less boring. The reasons for this increased attractiveness were the higher autonomy in learning and cooperation within the groups. About 70 % of the students characterized the cooperation in a jigsaw classroom as more intense and the learning as more attractive than in a normal classroom. More than 80 % of the students stated that they learned more and that they worked much more intensely. The feedback from learning with the card index was comparably positive. This project provided the first results on using this method in science teaching in Germany. Opinions on learning with the help of the Internet for the lead acid accumulator differed. Some students liked the approach, while others did not. Web-based learning seemed to be interesting for some students, but not well liked by all (Figure 8).

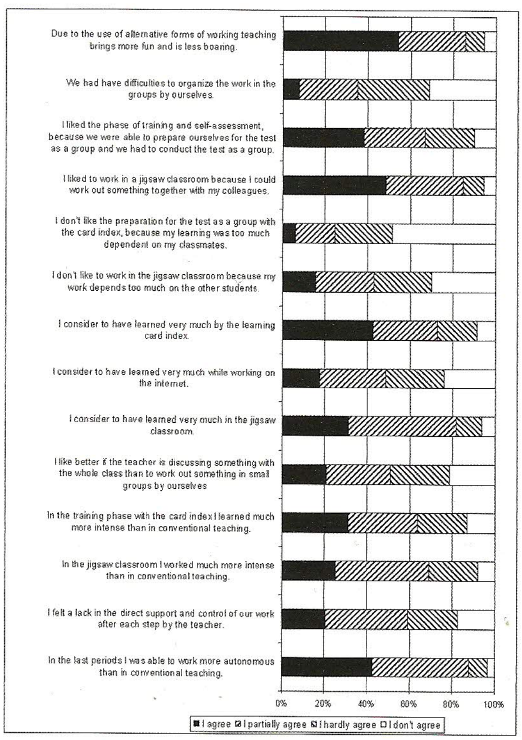


Figure 8. Results from the Likert-type Questionnaire (N=232)

Discussion

This study is an example of curriculum development using Participatory Action Research (PAR). We interpret the process of cooperation between practicing teachers and university researchers within PAR and its results as being very successful. This approach means a change in the classroom organization, in the learning of the practitioners, and in the overall applicability and success of a lesson plan. An objective measurement of the effectiveness of this approach cannot be provided, but teachers' opinions and their comparison with previous experiences allow some insights into the changes in teaching practice facilitated by the project. Teachers and advisors from the university unanimously agreed that the new lesson plan was successful in many ways, due to the path of its development and its cyclical optimization strategy.

From their past and current experiences, both the teachers and researchers consider the changes concerning the new textual approach and the implementation of student-oriented and cooperative learning to be an avenue with high potential for improving science teaching. Even though the topic was difficult and the demands were quite high, the students autonomously managed their learning based on the cyclically-developed teaching strategy and materials. Students' performance on the post-test can definitely be interpreted as promising, taking into consideration that experienced teachers rated it as really demanding. This success begs for further investigations of putting the learning process more firmly into the hands of the learners by using self-directing forms of cooperative learning. We should not be reluctant to ask students to learn autonomously in contexts that do not start with scientific content. The cumulative evidence from the project clearly indicates that science teaching should be rather contextualized towards everyday life, especially in lower secondary science teaching. The study also yielded evidence indicating that similar methods can make science teaching more attractive, and science learning more effective and sustainable.

Acknowledgements

We acknowledge the contributions of Dr. U. Willeke, H. Schultheis, M. Haverkamp, U. Knoop and Dr. S. Kienast and their students while testing the lesson plan, as well as P. Wlotzka, B. Most, D. Volke, T. Witteck, and J. Beyer for their contributions in discussing the lesson plan within the PAR group meetings.

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